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OCTOBER 20, 1974

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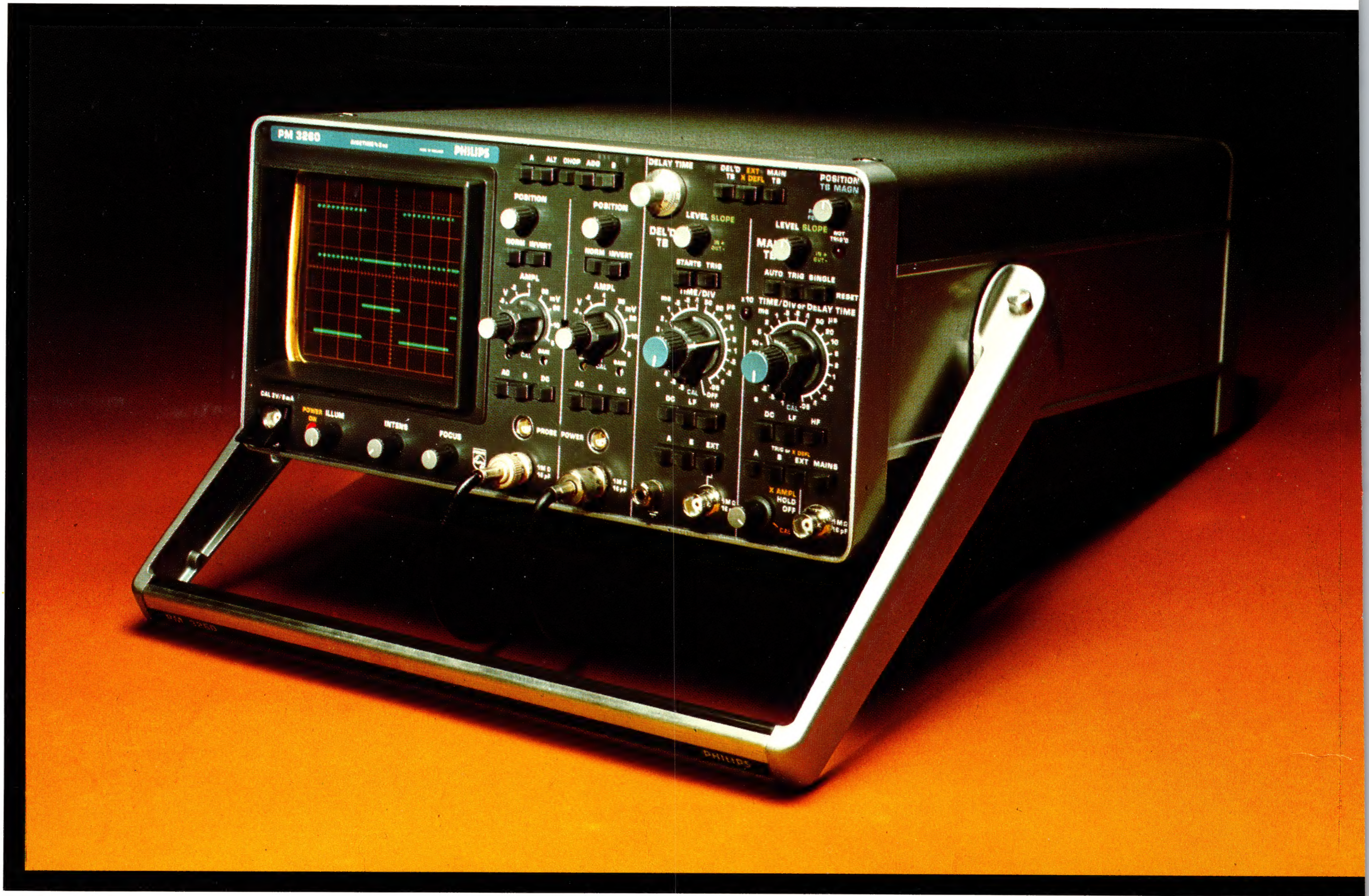
Designers' guide to:
Switching regulators

DAC/ADC contest winners
develop novel designs

Tape carrier technology exhibits extremely broad capabilities



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EXCLUSIVELY FOR DESIGNERS AND
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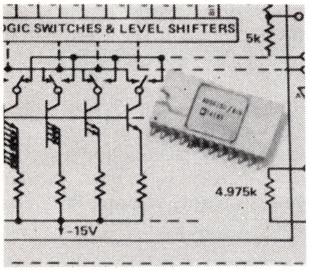
Tape-carrier IC's .. pg. 30



IC D/A converter .. pg. 94

COVER

Tie an amber ribbon of polyimide film around your next circuit design and you might save both space and money. AMP, Inc., Harrisburg, PA supplied our handsome cover photo. The related story begins on pg. 30.

DESIGN NEWS

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EDN DESIGN AWARDS **86**
Simple 10 kHz V/F features differential inputs . . . No table is needed to calculate logarithms in any base . . . Circuit combines integrate, sample and hold functions . . . An analog multiplexer makes an ideal CMOS output driver.

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IC D/A converter surpasses hybrid and modular devices **94**

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BPA ABP

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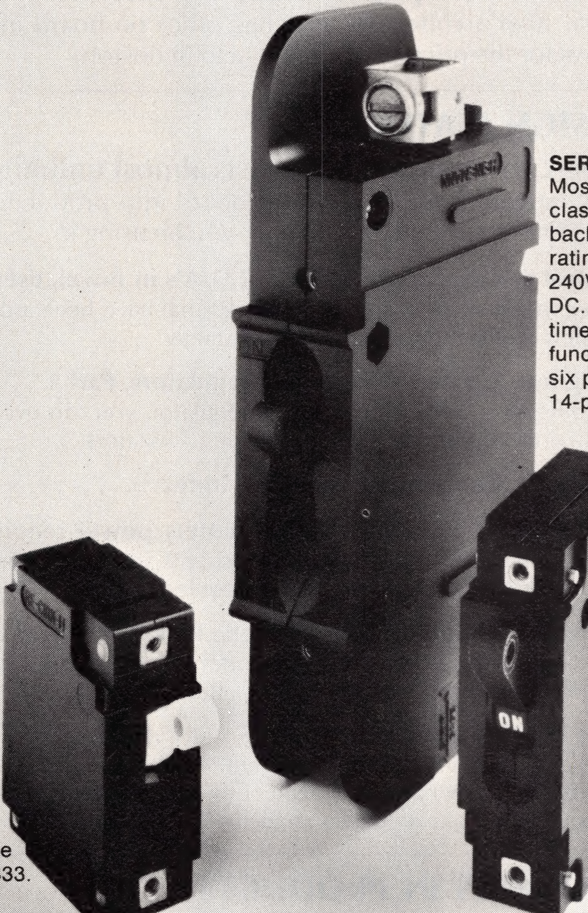
BIG 3.



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And with good reason. These three product lines are broad enough and deep enough to handle almost any OEM application.

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Your nearby Heinemann representative has complete information on the Big 3, as well as other Heinemann breakers, and can assist in recommending specific models for your application. He'll also tell you about our new stock program, called Quick-Draw, through which you can generally get a reasonable quantity of standard breakers in a few days, sometimes even overnight.

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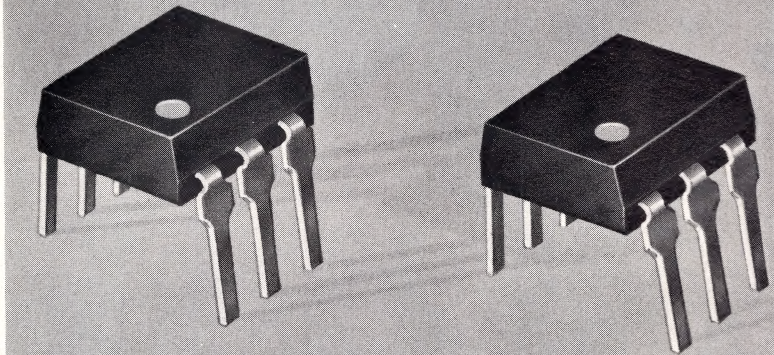

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Semiconductor Products Department, Syracuse, N.Y.

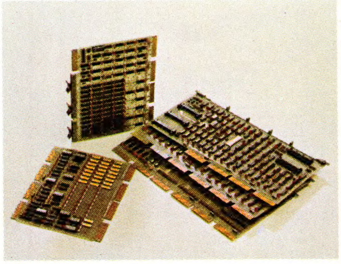
GENERAL ELECTRIC

The KIT-8/A component computer gives you minicomputer power at a microprocessor price.

$572 in quantities of a hundred. (CPU & 1K RAM.)

We've put the world's most experienced minicomputer, the PDP-8, on a single board and called it the KIT-8/A.

And we've done it using proven, readily-available, multi-source MSI semiconductor technology.



The KIT-8/A and option boards.

The KIT-8/A will give you speed and performance at a very low price. It's a full-scale 12-bit computer, the latest in the PDP-8 family. With 1.5 μsec cycle time, a huge, healthy software library, and the same powerful instruction set as the PDP-8/E. And it's fully compatible with most PDP-8 family hardware, operating systems, and high-level programming languages like BASIC, FORTRAN IV, and FOCAL.

The Omnibus™ backplane makes it easy to interface the KIT-8/A directly to more than 60 PDP-8 options and peripherals.

To make your life even easier, we've made the seven most-requested options available on two option boards. On one board, we've put the serial-line interface, 12-bit parallel I/O, front-panel control and real-time clock. On the other, we've put the bootstrap loader, power-fail/auto-restart, and memory extension.

We've employed expandable semiconductor memory to enable you to tailor your memory capacity to your needs, from 1K to 32K words. Choose ROM, RAM, PROM, or ROM/RAM combinations – mix and match to suit your application.

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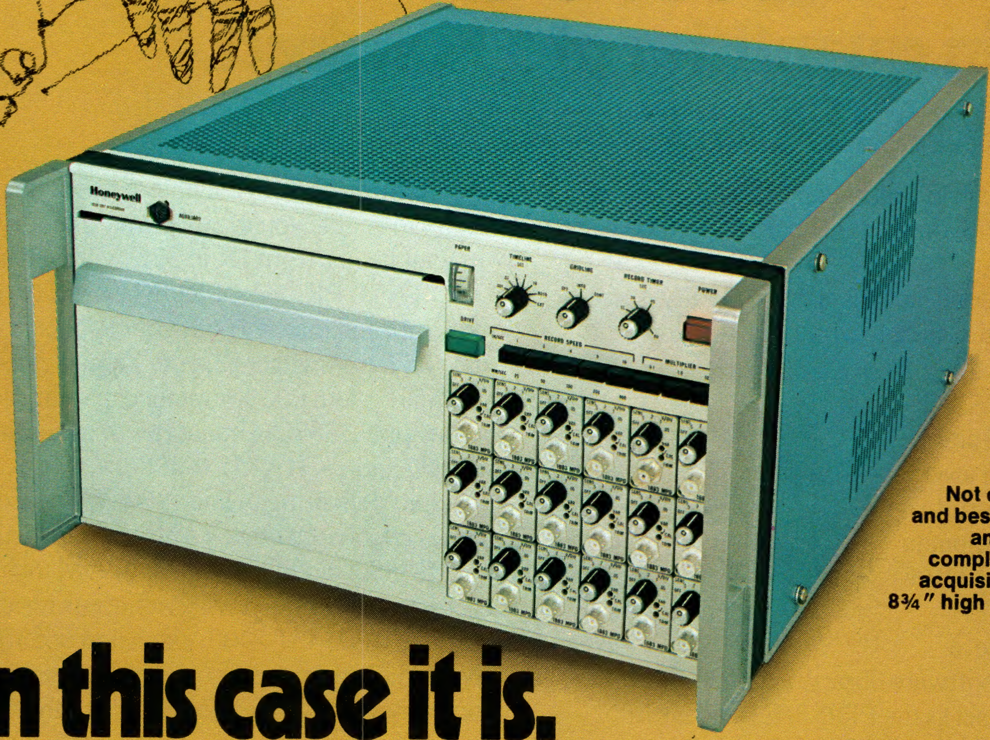

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Want to know more? Write or call our expert, Lloyd Moyer, Honeywell Test Instruments Division, P.O. Box 5227, Denver, CO 80217. (303) 771-4700.

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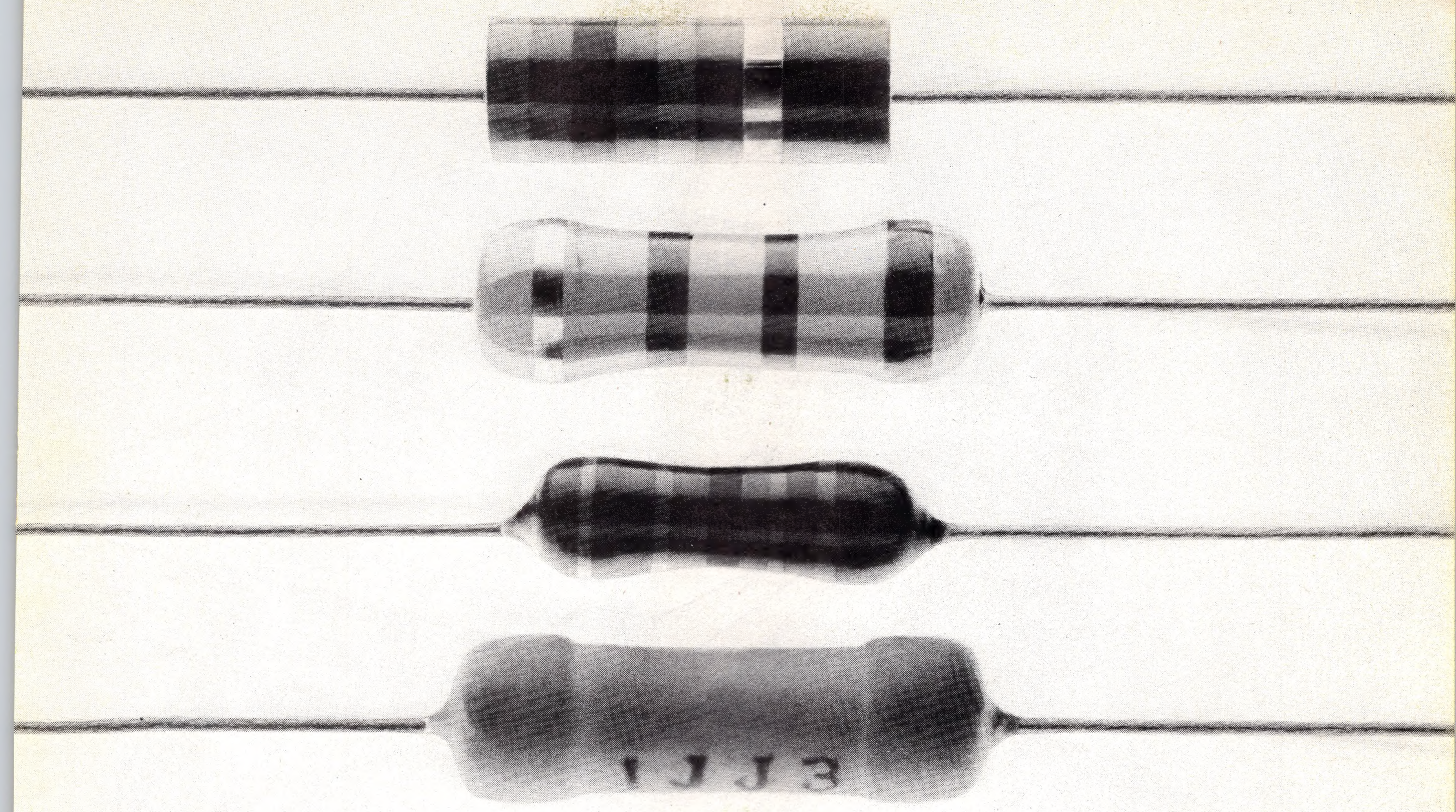

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All are readily available. All at a reasonable price. All made with the kind of quality that delivers high performance. It's what you expect from Panasonic. For more information on Panasonic fixed resistors, fill out this coupon.

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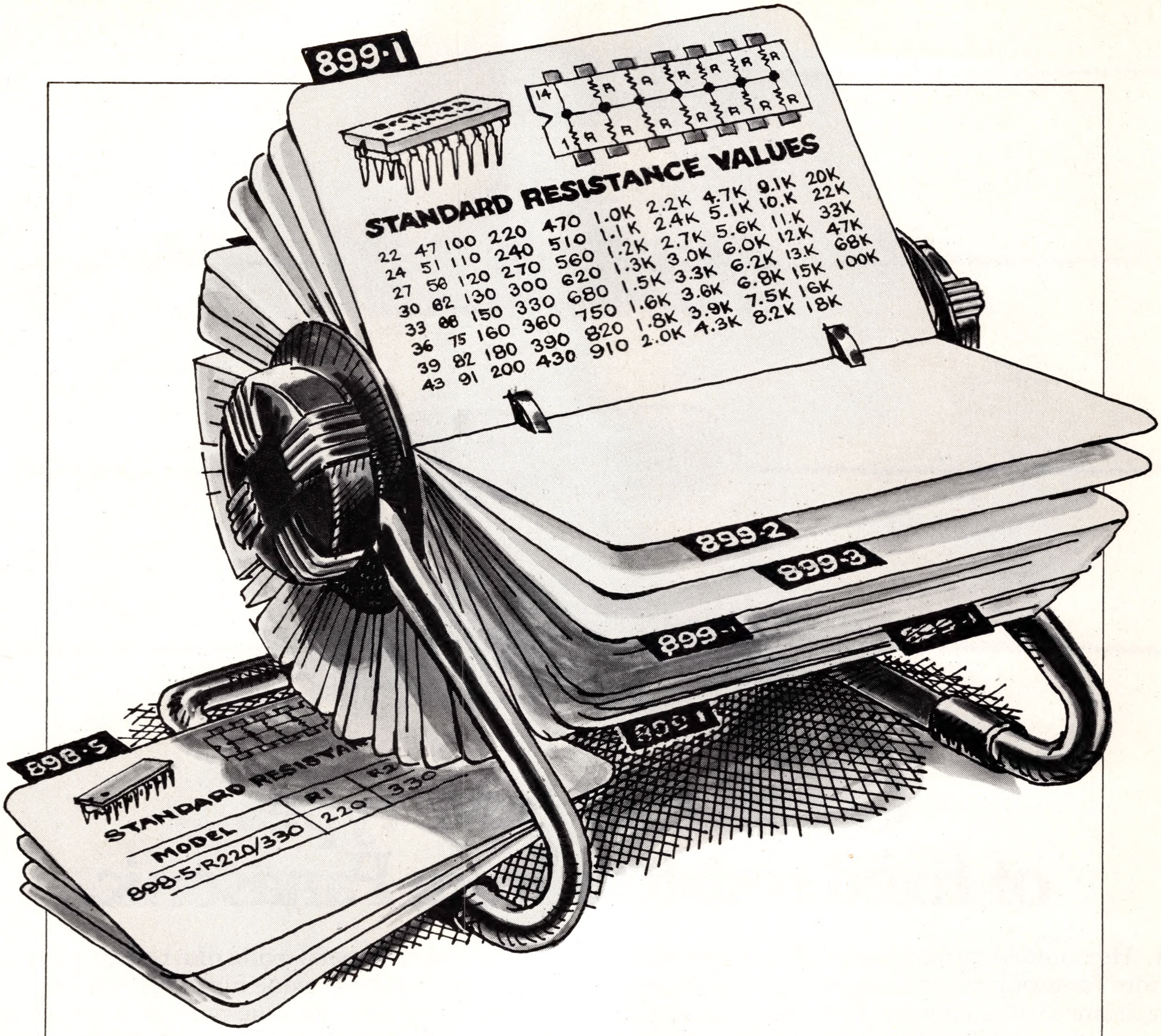
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33 68 150 330 680 1.5K 3.3K 6.2K 13.K 68K
36 75 160 360 750 1.6K 3.6K 6.8K 15K 100K
39 82 180 390 820 1.8K 3.9K 7.5K 16K
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RESNET DIPs are dimensionally uniform, ideal for automatic insertion techniques. They're also laser-tailored for precise resistance values. And every part is 100% tested.

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Considering breadth of line, quality, availability, and good pricing, you don't have to look farther than Beckman for standard resistor networks. Or for expertly produced custom versions as well.

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EDITORIAL

Musings on trade shows and conventions

After having just gone through the rigors of another trade show, some observations are in order. I'm asked constantly what I thought of it, particularly about the exhibit section. Unfortunately, my opinion and 25¢ might get you a cup of coffee. What counts is what the exhibitors think, for they are the ones who shell out a good amount of money to be there. The same goes for those companies who pay the tab for attendees.

So what about the most recent WESCON? There are those who shout gloom and doom over declining numbers of both exhibitors and attendees. However, most who attended WESCON were quite pleased with the entire affair. As usual, WESCON was well organized and well run. The organizers were satisfied that projected attendance figures (30,000) actually materialized, even though these were far below the peaks attained in the sixties. The lower figures can be rationalized in many ways: tight budgets, business slumps, absence of semiconductor manufacturers, too horizontal and more.

How valid these arguments are is open to question. If you or I had a clear-cut answer, we'd probably get rich. However, why do we so blithly accept this situation as "that's the way it is," while at the same time similar shows in Europe are so successful? The latter are well attended and there is no lack of exhibitors.

Perhaps this question has been raised many times in the past; however, I believe it needs more exposure. One must ask, "What is the purpose of trade shows?" Why expend considerable dollars to exhibit or send people to attend them? In Europe, the answer is to do business. Here, it is exposure! There's a vast difference.

The argument for and against selling "on the floor" continues, with those against still holding the edge. They seem to think it demeaning to sell on the floor—but why not? It works elsewhere! The trade show is a great place for buyers to have products demonstrated and to compare them all in a single day. It makes sense to me and it should make sense likewise to both exhibitors and to companies who foot the expense for attending engineers. And the return on investment is more readily measurable.

You, who design with and use those products exhibited at trade shows, are the ones who will determine their ultimate fate. What's your opinion?

Roy W. Forsberg

Editor

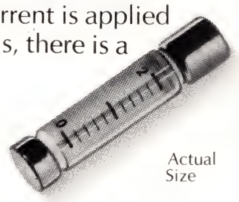
At last!
A time meter so simple, so low in cost you can use it in quantity on the equipment you design.

Install these newly developed electrochemical elapsed time indicators on equipment and components to get accurate records of operating time. The indicators cost less than $1.00 in large OEM quantities and are extremely compact... about the size of an ordinary automotive fuse. 1000, 2000, 5000 and 10,000 hour meters are available. Current consumption for a 1000 hour unit is only 50 microamps.

The indicators operate on a simple columetry principle. When a controlled DC current is applied across the terminals, there is a precise build up of a copper column in the glass tube, calibrated in hourly increments. Readouts are direct and non-reversible. Shock or vibration have little effect on either operation or accuracy. In fact, the indicators have been conservatively rated for 75 g's shock.

Try these time meters on the equipment you design. You'll find them ideal for warranty validation... to determine overhaul, calibration or replacement periods... or for most any preventive maintenance operation.

Send for information now!



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Tiny package...tiny price...
ideal to monitor operating time for maintenance, warranty validation.

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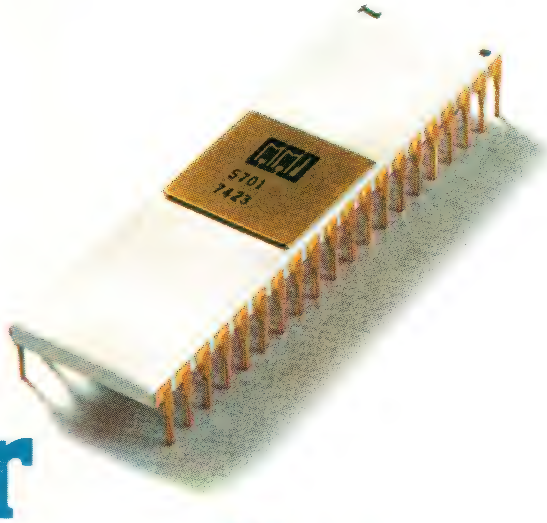
The first bipolar microcontroller.



Monolithic Memories' bipolar microcontroller.
It's a complete 4-bit expandable
TTL/LSI data slice.
A single chip in a 40-pin DIP.

And you thought we only made memories.

MMI's bipola

Our microcontroller is flexible. Expandable. Something you design with, not around.

When we announced our 10K ROM, we proved that bipolar processing could match MOS memory densities and still keep all the product advantages of the Schottky TTL. Now we're proving it again in logic. Monolithic Memories has driven ahead to the next major growth step in device integration in the world of logic. The MMI 5701/6701 bipolar microcontroller is the result.

It's a natural stage in the development of bipolar integration following the evolution of logic technology from discretes to MSI to LSI. But with complexity of over 1000 gates, our microcontroller deserves a descriptive title that's even beyond LSI.

What's included:

MMI's versatile microcontroller, designed to be used as a 4-bit processor slice of a conventional CPU, can also be easily designed into peripheral controllers where Schottky TTL speeds are required. Or you might want to use it in a host processor to control several slow microprocessors. Its two-address capability and nano-instructions let you design 200-nanosecond-cycle-time CPU's or emulate conventional machines by adding a few off-chip ROMs/P.ROMs for your microprograms. (MMI can easily supply the supporting ROMs, P.ROMs and RAMs. Even build the boards to your specs.)

The 5701/6701 will handle the data flow section of most computers. It's expandable in 4-bit increments without any significant speed penalty. Look-ahead outputs are included. 16 general purpose accumulators on the chip give you the computing power of the top-line 16-bit minis or 24- and 32-bit computers.

In conventional TTL equivalents, the 5701/6701 does what it now takes 25 MSI parts to do. Saves 375 I/O pins, 30 square inches of printed circuit board area and 5.6 watts of power: The savings on parts, pins and power speak for themselves. (See chart)

Process, Power and Performance

MMI's 5701/6701 (Mil/Commercial) microcontroller is a standard Schottky bipolar single-layer-metal device. Needs only 5V and ground. All inputs and outputs are TTL compatible. The 5701 is specifically designed to dissipate maximum power at low temp and minimum power at high temperature for improved mil temp range performance and reliability.

Speed? The 6701 can perform complex multiple operations which are performed in each cycle without timing problems. Fetch two operands, subtract, shift, and store, in one 200ns cycle! $(\overrightarrow{A_i - B_j} \rightarrow B_j)$

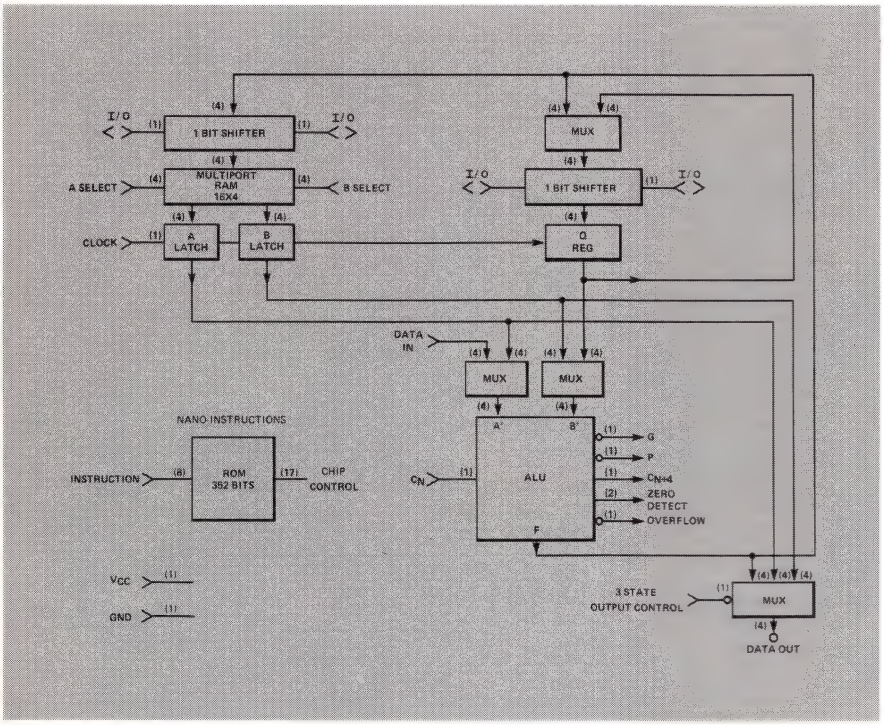
The MMI 5701/6701 microcontroller features:

1. Over 1000-gate complexity Schottky LSI.
2. Proven reliability of single-layer-metal process.
3. 36 instructions—21 arithmetic, 15 logic, and shifting capability with overflow detection. Active high or active low logic.
4. Performs multiple nano-instructions such as fetch, subtract, shift and store in one cycle. 200ns max. (Over temp and V_{cc}).
5. Replaces 25 TTL MSI packages; saves 5.6 watts.
6. 16 directly addressable 2-port general purpose accumulators. Full 2-address capability, some 3-register operations.
7. Separate on-chip register for use as a scratchpad or accumulator extension.
8. Direct data-in and accumulator operations.
9. Separate low fan-in data input bus and a 3-state output bus.
10. Expandable to handle N-bit words with full carry look-ahead capability.
11. Both zero detect and overflow conditions are brought out.

Function	TTL#	#14 Pin or #16 Pin Pkgs.	#24 Pin Pkgs.	Advertised Gate Complexity (Each Pkg.)	Gate Complexity Total	Typical Power Each (Watts)	Total Power (Watts)
32 x 9 & 8 x 8 ROMs	7488	3		70	210	.50	1.50
16 x 4 Multiport RAM	74172		4	110*	440	.56	2.24
Arithmetic Logic Unit	74181		1	75	75	.55	.55
Storage Latches	7475	2		28	56	.16	.32
J-K Flip Flop (Q Reg)	74107	2		22	44	.10	.20
4 to 1 MUX	74153	6		16	96	.20	1.20
O/I True Complement	74H87	2		18	36	.27	.54
Dual 4 Bit Select	74157	2		15	30	.15	.30
Quad 2 to 1 MUX with 3 State Outputs	74S257	2		15	30	.30	.60
3 State Buffer	DM8094	1		5	5	.18	.18
Totals		20	5		1022		6.63

*NOTE: The 74172 is advertised at 201 gate complexity but we are using only 2 of the 3 address capability, hence we have counted it as 110 gates.

microcontroller.



Where you can use it

The most appealing application for this powerful new device is in upgrading or replacing existing CPU's while maintaining all your existing software. Four of our 6701's, for instance, with about 24 other standard TTL parts, can emulate a 110-package 16-bit mini-level computer.

Equally important applications for MMI's 5701/6701 are in distributed processing applications. Its TTL speed in communications processors improves bit packing, and lowers phone line costs. Processing speed is also a key factor in concentrator applications for POS systems, intelligent terminals and other multiprocessors.

The ability to implement special purpose dedicated instruction sets makes our 6701 a perfect fit for machine and process control, navigation systems, and traffic control applications. Most systems using 74181, 9340, 9341 or 74S281 ALU's can now get better performance with our 6701.

How to get into it

If you design with TTL and have existing software, MMI's bipolar microcontroller fits right in. Because it's 4-bit expandable, you can tailor it to fit your system. Easy. And our applications people will be glad to help.

Best of all, you'll find prices on the MMI 5701/6701 are competitive to standard TTL. Learn more about prices, specs and delivery. Write **Monolithic Memories, Inc.,** 1165 East Arques Avenue, Sunnyvale, CA 94086. Better yet, call your local MMI sales office or representative listed below.

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40% lighter than most portable recorders, the compact 5600C has a full IRIG-compatible 14 channels of record/reproduce.

This lab quality take-along can be powered from 12, 24 or 28V dc or any 47-400 Hz ac source. So you can test anything, anywhere.

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I_C A	V_{CEO}† V	h_{FE}	$V_{CE\,(sat)}$ V	Type No.	Package (Modified)	Polarity	Power Dissipation 100°C Case W
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5	300	1000 @ $I_C = 3A$	1.5* @ 5A	U2T303	TO-3	NPN	50

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UNITRODE
580 PLEASANT STREET, WATERTOWN, MA 02172

Don't count submarine telephone cables out yet

Earle Dilatush, Associate Editor

Heave Ho! South Atlantic cable's shallow-water section being hauled ashore at Sesimbra, Portugal. The cable runs from Capetown, S. Africa to Lisbon, Portugal. (*ITT*)

Despite a common misconception that communication satellites have made submarine cables obsolete, their construction and usage continue to grow rapidly. Just this past June, for example, North America's transatlantic telephone cable circuits doubled when a new 1840-circuit undersea cable went into service.

Why not go all-satellite?

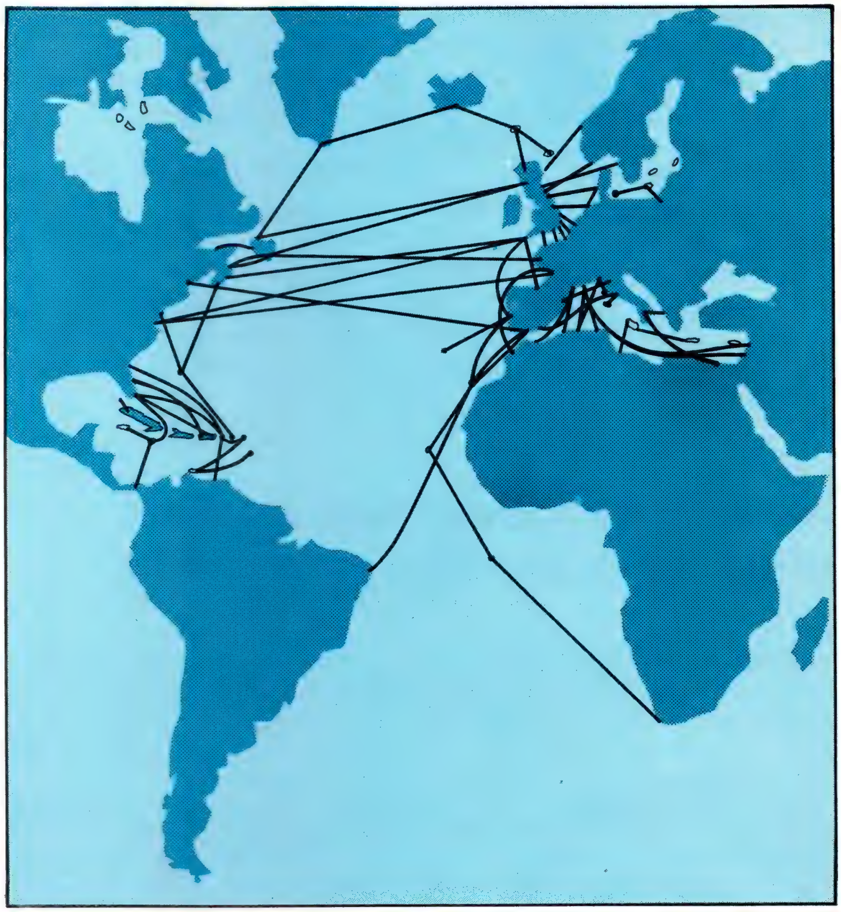
In view of recent satellite developments, many people wonder about the activity in submarine cables. After all, these have been the standard for intercontinental communication since laying of the 1866 telegraph cable. The answer is simply that submarine cable technology has also been advancing rapidly, keeping cable communication competitive with that using satellites. A modern cable system provides reliable, secure, high-quality transmission at a cost below satellite service. This cost drops steadily with each new generation of cable systems.

The first Trans-Atlantic Telephone cable (TAT-1), installed in 1956, had a capacity of 48 conversations. Contrast that with the newest cable design for use in the U.K.-Belgium route. This can handle 5500 telephone circuits over a 1200-mile route. It will carry television signals as well as telephone—the only very-long-distance cable designed with that type of capability. Engineers believe this design can be useful for up to 4000 miles, making it suitable for long intercontinental routes.

Satellites and submarine cables complement each other. Submarine cables serve better where there is large traffic between two points, such as U.S. to Europe. Satellites, however, are economical on long "thin" routes with less traffic and have been very useful in providing international service to developing nations. They permit communication from any ground station to any other within range, giving flexible service to small countries with low traffic density.

When the first communications satellite, Early Bird, was launched, it supplied 240 transatlantic circuits and was thought to herald the end of submarine cables, at least on long-haul routes. Cable installations did slow down for a time, but soon picked up because of decreasing costs. Since 1956, the cost of each circuit mile of cable has decreased by a factor of 30, principally because more and more channels are being packed

The shortest distance between two points is a cable; it's faster than a satellite link. These are the submarine cable networks in the Atlantic, Caribbean and Mediterranean seas as of 1974. The new TAT-6 will shortly add 4000 circuits, doubling the transatlantic path. (*ITT*)



into each new cable.

Cables provide long life

Cables have a designed life of 25 years. This means that once they are placed on the bed of the ocean, they—with their millions of components—are expected to operate perfectly 24 hours per day, day in and day out, for 25 years! Experience has shown this to be attainable. Every submarine telephone cable system laid since the first small one in 1926 from the U.K. to Belgium is still conveying rated traffic. On rare occasions they may be cut by trawls or anchors in the shallow-water areas. But the outages can be repaired in a few hours to a few days.

Satellites, on the other hand, have been much more prone to technical problems. None has yet realized its design life, with the exception of the very first Early Bird that lasted two years. Obviously, satellites are difficult if not impossible to repair.

At present, there are six satellites in orbit over the Atlantic, Pacific and Indian oceans. All of these, except the Indian-ocean satellite, are complemented by cable systems. The low volume of traffic in Asia and Africa does not yet warrant an Indian-ocean cable.

Traffic fixes the choice

Traffic and projected growth of traffic, even though difficult to define, are the major factors influencing the design of telecommunication networks.

Countries with the highest volume of traffic have invested in both satellite and cables. Currently there are over 140 submarine cable systems throughout the world and there are 79 satellite earth stations, using 89 antennas, in 53 countries. This dual arrangement safeguards the traffic by providing alternative facilities.

The vast majority of these facilities are in North America and Europe. In the past 10 years the number of telephone calls between the U.K. and North America increased from 900,000 a year to 8.5 million. By 1980 the telephone authorities plan to handle 30 million calls a year. To fill these needs, undersea communication cables are rapidly expanding, with the number of circuit miles doubling every two to three years.

Some pro's and con's

The existence of both cable and satellite facilities allows alternative routing in the event of outage on one or the other. However, the quality of communication must be considered.

Voice quality over a satellite system is normally good, but the waves must travel as much as 40,000 miles from the transmitter up to the satellite and down again to the receiver. This causes almost a 1-sec delay, which compounds technical problems. The delay is so great that two satellite "hops" are not permitted in tandem on a phone circuit. By comparison, the delays are undetectable in a cable system of several thousand miles.

For transoceanic transmission of color-TV pictures, the satellite has the edge because of its circuit capacity. In a live transmission, color-television channels use the equivalent of about 1000 telephone circuits. Also, it is not particularly important if a program broadcast in America is received in Britain with a half-second delay.

Cable transmission offers some other advantages, too. One is the lack of radio-spectrum pollution. Waves transmitted over cables are restricted to the interior of the cable and do not pollute the "ether." Thus, they cannot interfere with other vital services such as communication, radar and aerial navigation. Nor can they be intercepted by unauthorized agencies.

Conversely, since all circuits on a cable are guarded by a metallic cable wrapping that is impervious to radio waves, cable transmission does not receive interference from existing radio services and cannot be intentionally jammed.

Today's network is big

Since the TAT-1 cable in 1956 (144,000 circuit miles), the world's submarine cable network has expanded rapidly to its present size of about 28.7-million circuit miles. This represents an investment of roughly $1.2 billion.

To meet the exploding need for worldwide communications, an additional 26.8-million circuit miles of cable, costing about $530 million, are being readied. Also, plans are on the drawing boards for roughly another 3.3-million circuit miles, representing an additional expenditure of $90 million. ☐

Aerial map architecture matches other on-board instrumentation

Global aerial chart information now is being reconstructed into an aircraft cockpit display for navigational purposes. Laser-hologram technology and the notion of "cassette" have merged.

Extending from Navy and NASA development programs, a holographic moving map display system (**Fig. 1**) was constructed by a team of RCA-Burlington electronic engineers. The dedicated system provides an aircraft pilot with automated management of on-board aerial maps from flight plan to touch-down. Furthermore, it elevates this flight support function to the architectural level of other on-board instrumentation such as altimeters, auto-pilots, radios and radars (**Table 1**).

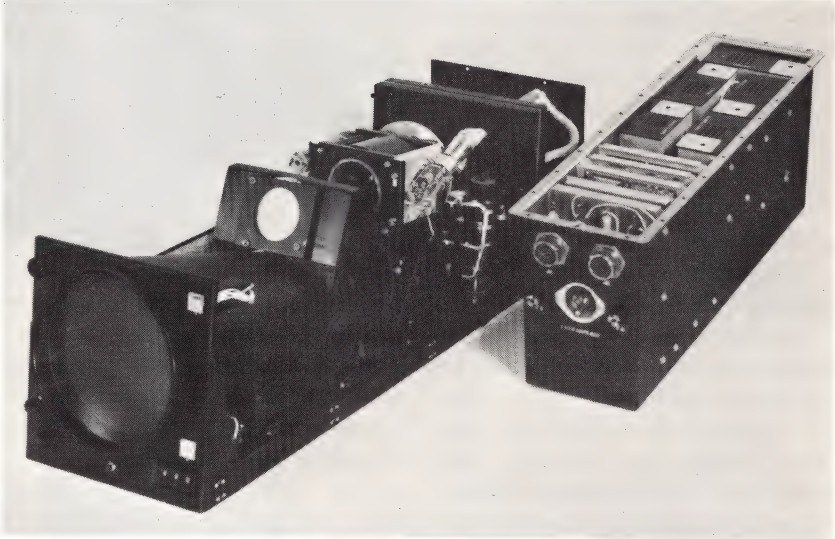


Fig. 1—A dual-package system, the display screen is housed with a light source, reconstruction and readout optics, a film transport and control logic. Other unit contains power supplies and transport drive electronics. 350W tungsten lamp handles the in-flight reconstruction.

Resolution	7 to 8 1p/mm, 65% response
Viewing area	Circular, 6-in. diameter
Color fidelity	Equivalent to existing aerial charts
Brightness	Acceptable for viewing (12:1 contrast) in a 2000-fL environment
Configuration	Two units: power supply and display unit
Display size	8-1/4 x 8-1/4 x 26 in.
Display weight	18 lb
Power supply size	19 x 7-1/2 x 4-7/8-in.
Power supply weight	28 lb, 9 oz
Storage technique	
Map information	Focused-image hologram
Indexing information	Modified Fraunhofer hologram
Registration information	Fresnel hologram
Storage density	12.5 x 12.5-in. chart segment on 12 x 12-mm hologram, 500 holograms per cassette.
Access time	Any one of 500 frames in under 6 sec; ±30 frames in under 300 msec.
Image motion	X-Y translation over ±3-in., 360° rotation
Power requirement	600W, 115V 60Hz
Projection source power	370W

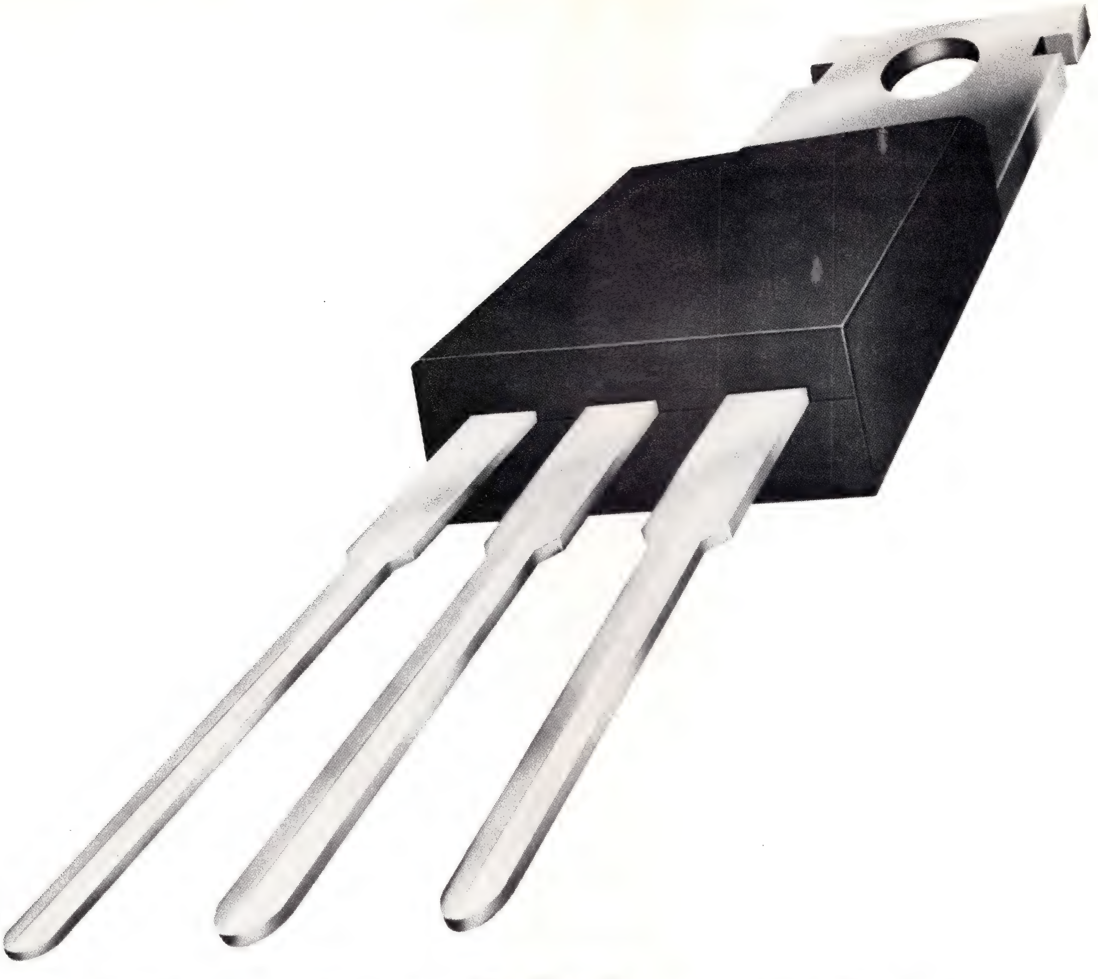
Table 1—Moving map display characteristics.

Lasers and holograms

Holography has been chosen because of its numerous advantages over conventional image storage methods. Realized by this system are the following:

- Precise registration of stored images independent of storage medium position
- Highly redundant recording
- Multiple image recording
- Rapid and inexpensive duplication

Today's techniques enable reconstruction of a map of the entire world with thirteen thousand 12-1/2×12-1/2-in. map segments. Imagine each segment reduced to a 12×12-mm size hologram with indexing and



The RCA 300 volt Triac. It can knock the 400 volt triac right out of the box.

The RCA T2800C is a solid 300 volt, 8 amp. triac. And sets a whole new standard for the industry. Until now, if you wanted added protection for 120V line operation, you were forced to go from 200 volts all the way up to 400 volts. More protection than you needed. More price than you should be paying. Matter of fact, right now there are a lot of black boxes containing 400 volt triacs that could easily have used the RCA T2800C, 300 volt device.

It's rugged enough to handle just about any 120V line job you have in mind or that's 'on the boards'—from motor controls and solid state relays to power switching systems. It has features like: glass passivated junction, 100 A peak surge full-cycle current rating, shorted-emitter center-gate design, low switching losses, low thermal resistance and it comes in our rugged Versawatt package. Perfect for dependable operation in a 120 volt line non-consumer environment.

Another important feature is that you "buy it off the shelf" either from your local RCA distributor or directly from RCA Solid State.

Its 1K price is 96¢ — sufficiently lower than the 400V device to save you money while still playing it safe.

T2800 FAMILY

RCA TYPE	VOLTAGE RATING	1K PRICE
T2800B	200V	$0.88
T2800C	300V	0.96
T2800D	400V	1.04
T2800M	600V	1.50

For more information contact your local distributor or RCA Solid State, Section 50J20, Box 3200, Somerville, N.J. 08876. Phone (201) 722-3200, Ext. 3134.

For a free sample, send RCA a note under your company's letterhead stating the application.

RCA Solid State

International: RCA, Sunbury-on-Thames, U.K., or Fuji Building, 7-4 Kasumigaseki, 3-Chome, Chiyoda-Ku, Tokyo, Japan. In Canada: RCA Limited, Ste. Anne de Bellevue 810, Canada.

For more information, Circle No. 26

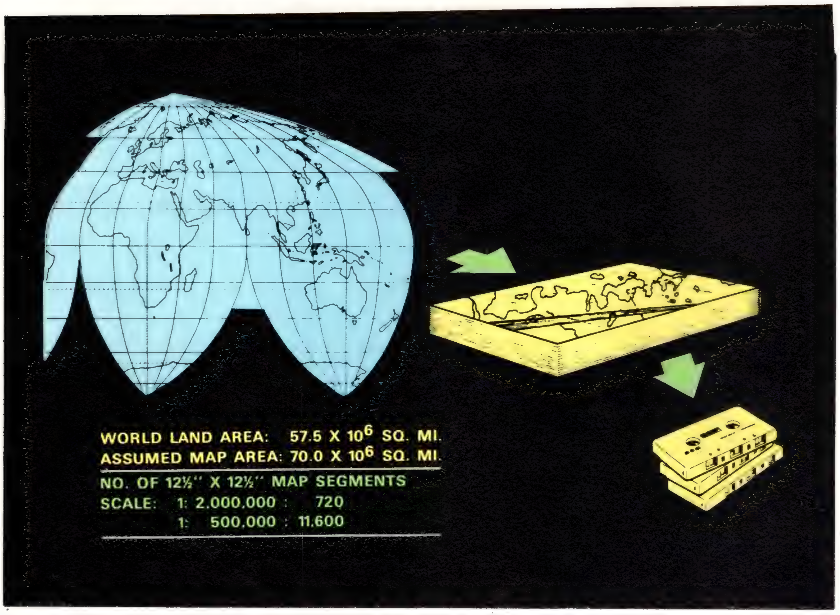

WORLD LAND AREA: 57.5 X 10^6 SQ. MI.
ASSUMED MAP AREA: 70.0 X 10^6 SQ. MI.
NO. OF 12½" X 12½" MAP SEGMENTS
SCALE: 1: 2,000,000 : 720
1: 500,000 : 11,600

Fig. 2—World map conversion maintains an east-west continuity for a 32-frame strip. This is followed by the abutting E-W strip such that a North-South course causes strip to strip jumps of 32 frames.

registration preserved. If 1000 are assembled on a roll, then 13 cassette rolls of holograms could reconstruct a map of the entire world (**Fig. 2**).

5-holograms per frame

Photoresist, deposited on a Kronar-tape base, was selected as the recording medium. Red, green and blue image information is embossed on one side of the tape while positioning and indexing information is embossed on the reverse side (**Fig. 3**).

The embossing process is performed in precise registration on a frame basis. Three-color separation is used in three successive exposure operations to produce overlaid focused-image holograms. Indexing information for retrieval purposes is recorded as a Fraunhofer hologram. The fifth hologram, superimposed on each frame, is a Fresnel. It provides the registration information to properly position the frame. Thus, five separate holograms of three different types are superimposed to provide map detail, retrieval and coordinate tracking functions.

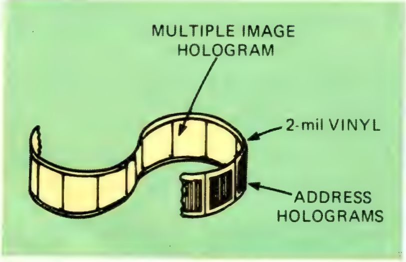


Fig. 3—The entire United States fits on one 35-mm roll! In fact, 13 cassette rolls of holograms could reconstruct a map of the entire world.

During preflight, a special reader annotates cassette maps. The pilot displays each frame and traces his flight path on to the holograms. A servo-controlled heated stylus moves over the hologram, removing fringe modulation where it passes. However, frame address and position information remain intact due to the redundant nature of holograms.

This technique also permits the addition of symbols, letters and numerals for navigational fixed points and other purposes. Expected cost of an entire tape is only $5. Therefore, it may be discarded after a single flight.

Flying on-course

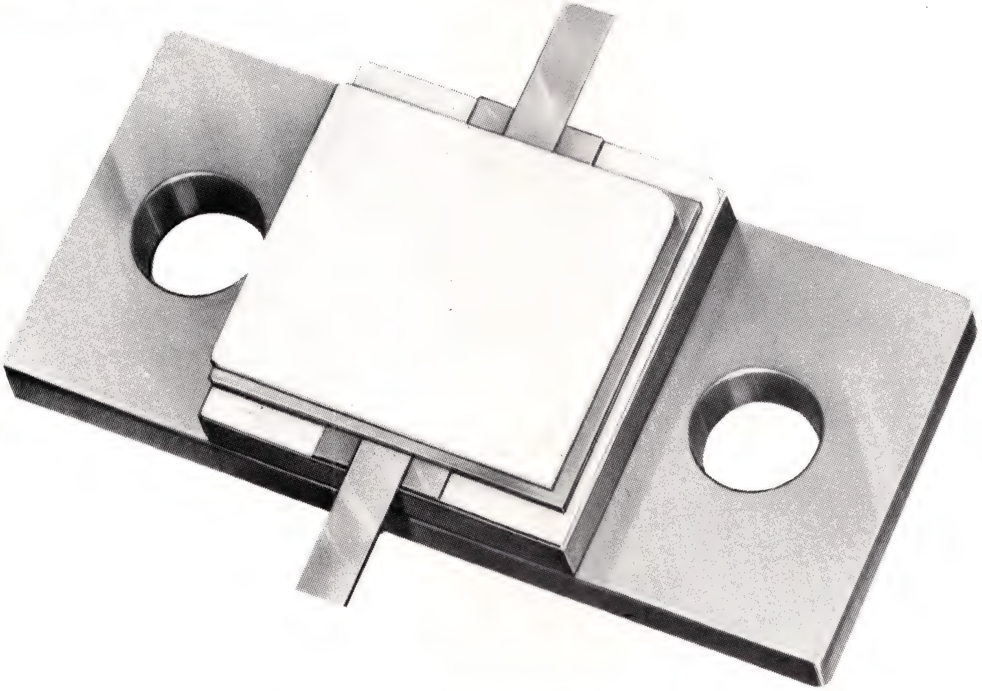
Normal map presentation in flight, an automatic tracking mode, maintains the aircraft's present map position. With a 20% frame overlap, display-refreshing is quite acceptable. Map orientation can be either "north-up" or "track-up." The pilot also can select a "look-ahead" mode or manually call any frame in the cassette and then return to auto mode.

Drawing on the flight-plan annotation, a dedicated on-board computer unrolls the cassette to provide the pilot with a bright 6-in. screen of moving map images that matches the panorama below (**Fig. 4**).

Truly an exhaustive application of hologram technology,

Fig. 4—Pilot can match the moving map display with the panorama below as he follows his flight plan.

When RCA says its 2023-12 GIGAMATCH delivers 12 watts at 2.3 GHz, 12 watts is what it delivers.



That's technology you can use.

If 12 watts is what you need at 2.0 to 2.3 GHz, 12 watts is what you're going to get. Because at RCA we're working to make our technical leadership important to your product's performance. And to you.

For example, we've used our experience on epitaxial and overlay emitter-electrode construction technologies to bring you the RCA 2023-12. It's internally matched for use in amplifier applications in the 2.0 to 2.3 GHz range.

The RCA 41044 discrete transistor is another case in point. Here's an RF power oscillator that delivers 350 milliwatts of power at 4.3 GHz.

At that frequency, that's a lot of performance.

And that's just the tip of the iceberg.

Last year, we announced 18 families and 29 types of products in the RF power area. Products such as the RCA 2000 and the RCA 3000 series. A new family of 2-GHz and 3-GHz microwave power transistors. A series in inventory, in quantity, and ready to ship.

This year, it's more. We've recently announced the RCA 2310 discrete transistor. We believe this device offers the highest power output for a single transistor to date (10w min.) for S-band telemetry service at 2.2 to 2.3 GHz.

And more is on the way.

In the high power microwave area, we're working on L-, S- and C-bands. Our line of GIGAMATCH devices (transistors with built-in input and output matching) is being expanded to cover the following additional frequency bands: 0.6-1.0 GHz, 1.2-1.4 GHz, 1.4-1.7 GHz, 1.7-2.0 GHz and 3.6-4.2 GHz.

All these devices will be usable at the frequencies and power outputs specified. So when you think of RF power devices that live up to their specifications, RCA should come to mind and you should contact your local RCA Solid State Distributor.

For data on new microwave transisitors write RCA Solid State, Section 50J20, Box 3200, Somerville, N.J. 08876. Phone (201) 722-3200 Ext. 3435.

RCA Solid State

A power house in RF transistors

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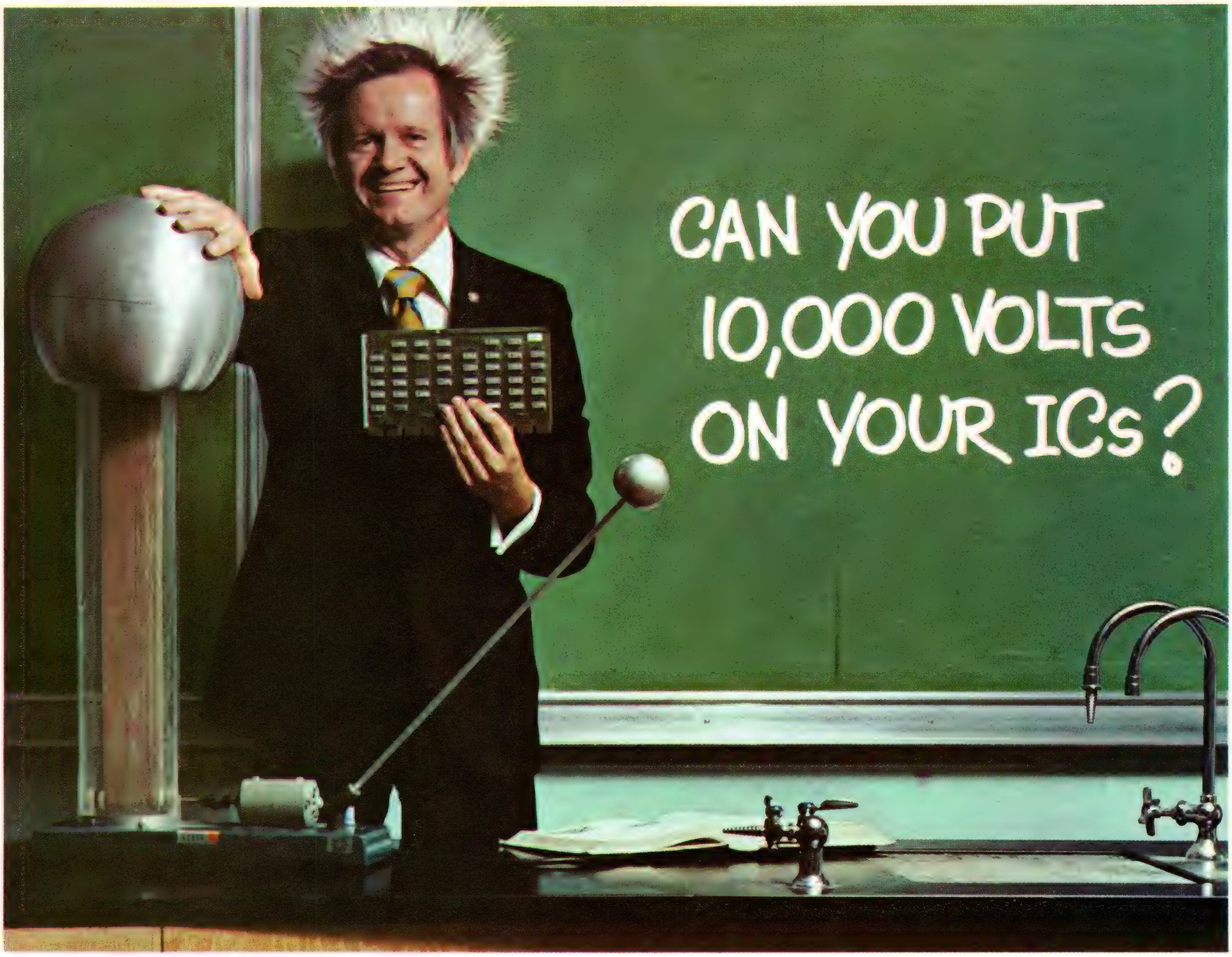
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the most dramatic aspect is that in-flight reconstruction is done not with a laser but with a 350W tungsten lamp. This is electronic wizardry at its best, again working for man in one of his most hostile environments.—*CD*

Two shows for the price of one to be held in Boston

Later this month, October 29-31, both the Northeast Electronics Research and Engineering Meeting (NEREM '74) and NEPCON/New England '74 will be held at the John B. Hynes Veterans' Auditorium, Boston, MA. Managements of NEREM and NEPCON have agreed on mutual visitation rights; however, students and children are not allowed at NEPCON.

An electronic packaging and production show, this is NEPCON's first visit to New England. NEPCON officials project more than 100 exhibitors using 200 booths, and attendance in the 6-8000 range.

NEREM '74 offers, in addition to an exhibit area with over 100 companies showing new electronic products and equipment, a wide-ranging technical program. This year the program features a broader coverage of disciplines and technologies than previous shows. Particular emphasis is on topics relevant to working engineers. Subjects will range from the traditional: mini and microcomputers, memories and communications, to nontraditional electronic areas: medical, automotive, transportation, postal service, digital TV and security systems.

Mini/micro seminar

A highlight of NEREM is a 2-day seminar on one of the hottest topics today, mini/microcomputers. The seminar, chaired by Andrew Knowles, Vice President, Digital Equipment Corp., will cover all aspects of the subject. During the first day, a silicon-on-sapphire mini, a microprogrammed processor, microprocessors, 4k RAM's and mini terminals will be examined. The second day will be devoted mostly to applications.

Advance registration for this seminar is $80 for IEEE members and $99 for nonmembers.

Another 2-day seminar with a similar fee structure will deal with modern communications and the computer.

Nontraditional electronics

A number of areas not thought of as traditional electronic markets fill out the technical program. For example, a full day is devoted to current medical engineering and its role in hospital communications and diagnostic instrumentation. How electronics are presently being used in the automobile and what the future holds is the subject of another session.

Use of electronics to help untangle the transportation snarl, applications of electronics in the postal service, and communications in security systems are other nontraditional markets to be addressed in this year's program.

Additional subjects of interest in the NEREM technical program include digital TV systems (image perception, picture structure, video generation and refresh memories) and energy problems facing the electronics industry today.—*RF*

Thin-Trim® capacitors

Tucked in the corner of this Pulsar Watch is a miniature capacitor which is used to trim the crystal. This Thin-Trim capacitor is one of our 9410 series, has an adjustment range of 7 to 45 pf., and is .200" x .200" x .050" thick. The Thin-Trim concept provides a variable device to replace fixed tuning techniques and cut-and-try methods of adjustment. Thin-Trim capacitors are available in a variety of lead configurations making them very easy to mount.

A smaller version of the 9410 is the 9402 series with a maximum capacitance value of 25 pf. These are perfect for applications in sub-miniature circuits such as ladies electronic wrist watches and phased array MIC's.

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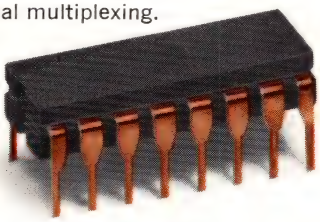

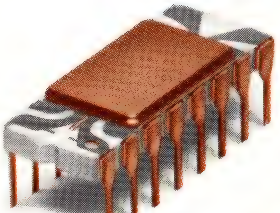

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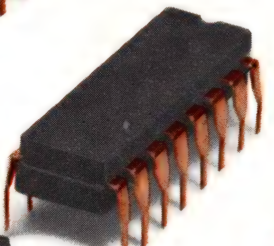
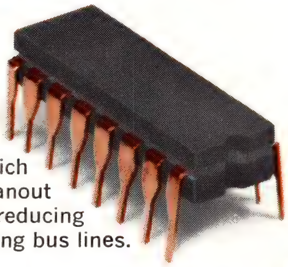
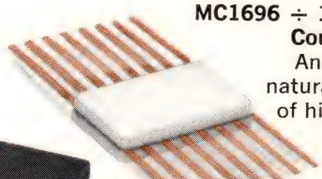


MC10194 Dual Simultaneous Bus Transceiv
Designed for high speed data transfer over multiport bus lines, increases message dens



MC10195 Hex Inverter/Buffer
Intended for MSI-rich designs for high-fanout clock driving and reducing stub lengths on long bus lines.



MC1696 ÷ 10, 1—GHz E Counter with Re
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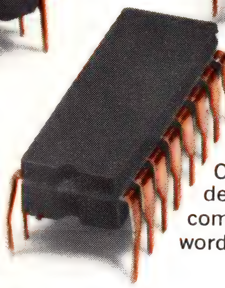
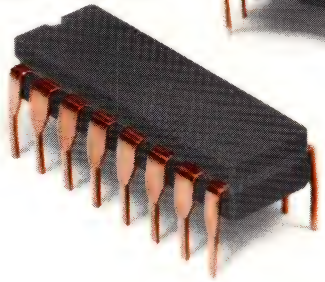
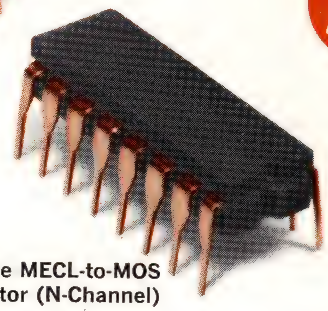


MC10166 5-Bit Comparator
Compare two 5-bit binary words. Connect multiple devices for comparing longer words.

MC10159 Quad 2-Input Multiplexer (Inverting Output)
A quad two channel multiplexer with enable. Input levels are inverted at the output.



MC10287 High-Speed 2-Bit Multiplier Useful as an array multiplier block. Two 4-bit words can be multiplied in 14 ns (typical).



MC10177 Triple MECL-to-MOS Translator (N-Channel)
Designed for NMOS memory systems as a read/write data/address driver. Drives high capacitive loads.

exer (Non-Inverting Output)	MC10158L	*	*	*
exer (Inverting Output)	MC10159L	*	*	*
or/Checker	MC10160L	MC10160P	MC10560L	MC10560F

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e Systems / Tracking Systems / Rocket Electronics / Deep Space Satellites /
Ground Stations / Digital Correlators

Decoder (Low)	MC10161L	MC10161P	MC10561L	MC10561F
Decoder (High)	MC10162L	MC10162P	MC10562L	MC10562F
ection Ckt. (IBM Pattern)	MC10163L	*	*	*

Quad 2-Input MUX W/Latch	MC10173L	MC10173P	*	*
Dual 4-to-1 Multiplexer	MC10174L	MC10174P	MC10574L	MC105
Quint Latch	MC10175L	MC10175P	MC10575L	MC105
Hex D Flip-Flop	MC10176L	MC10176P	*	*
Triple MECL-to-MOS Translator (N-Channel)	MC10177L	*	*	*
Binary Counter	MC10178L	MC10178P	*	*

us Receiver	MC10129L	—	—	—
Latch	MC10130L	MC10130P	MC10530L	MC10530F
Flip-Flop	MC10131L	MC10131P	MC10531L	MC10531F
UX W/Latch (Common Reset)	MC10132L	MC10132P	*	*
UNICATION — TDMA (Time-Division-Multiple-Access) / High Speed Modems / Satellite unications / Microwave Communications / Frequency Synthesizers / Data Delay Lines / Telemetry / Real-Time Signal Processors / Digital Filtering / Data Communications / Radar / Error Detection rrection Systems / Message Scramblers / Switching Systems / Video Signal Processors / ompressors / Telephone Computers				
atch	MC10133L	MC10133P	MC10533L	MC10533F
UX W/Latch (Separate Select)	MC10134L	MC10134P	*	*
K Master-Slave Flip-Flop	MC10135L	MC10135P	MC10535L	MC10535F

64-Bit RAM (64 x 1) (90 ohm Drive) (15 ns max)	MCM10140L	—	—
4-Bit Universal Shift Register	MC10141L	MC10141P	MC1
64-Bit RAM (64 x 1) (10 ns max)	MCM10142L	—	
INSTRUMENTATION — Frequency Meters / Counting Circuits / Nuclear Instrumentation Equipment / Medical Electronics / Laser Circuitry / Precision Timing / Oscilloscopes / Generators / Radar Systems / Correlators / Walsh Generators and Filters / Logic Test S Pulse Generators / Distance Measuring Equipment / Memory Testers / Mass Spectrome Prescalers / Spectrum Analysers			
8 x 2 Multiport Register File (RAM)	MCM10143L	—	—
256-Bit RAM (256 x 1) (30 ns max)	MCM10144L	—	
64-Bit RAM (16 x 4)	MCM10145L	—	
128-Bit RAM (128 x 1) (12 ns max)	MCM10147L	—	—
64-Bit RAM (64 x 1) (50 ohm Drive) (15 ns max)	MCM10148L	—	—
256 x 4 Factory PROM	MC10150AL	—	
Quad Latch (Negative Clock)	MC10153L	*	

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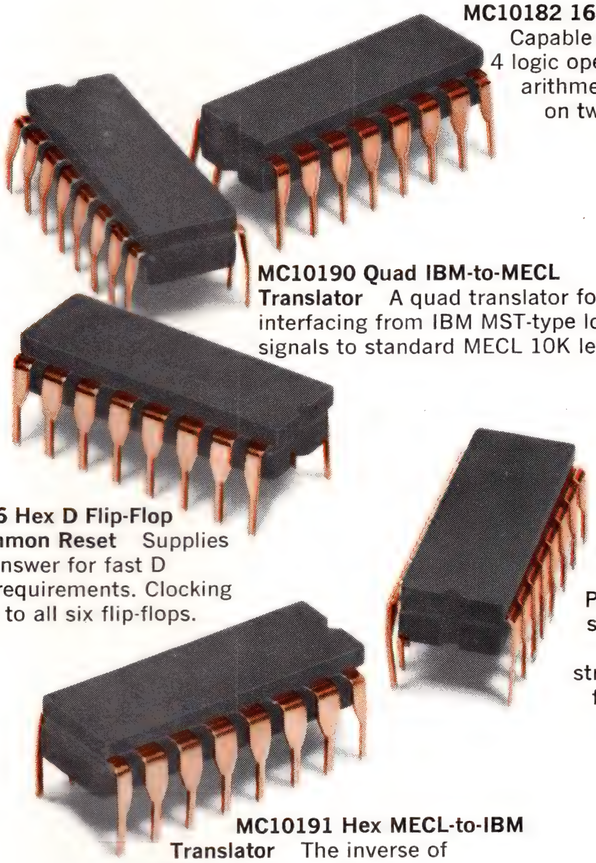

MC10182 16-Pin 2-Bit ALU Capable of performing 4 logic operations and 4 arithmetic operations on two 2-bit words.

MC10190 Quad IBM-to-MECL Translator A quad translator for interfacing from IBM MST-type logic signals to standard MECL 10K levels.

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D Flip-Flop W/Common Reset	MC10186L	*	*	*
d IBM-to-MECL Translator	MC10190L	*	*	*
MECL-to-IBM Translator	MC10191L	*	*	*
EAR — Video Gates / Video Amplifiers / Schmitt Triggers / Balanced Modulators / Commutating ers / Limiters				
or Detection/Correction Ckt. (Motorola Pattern)	MC10193L	*	*	*
Inverter/Buffer	MC10195L	*	*	*
AND Gate	MC10197L	*	*	*
h-Speed Dual 3-Input/3-Output OR Gate	MC10210L	MC10210P	*	*
h-Speed Dual 3-Input/3-Output NOR Gate	MC10211L	MC10211P	*	*

*Indicates scheduled package additions

Binary Counter (325 MHz typ)	MC1654	—	MC1
Voltage Controlled Multivibrator	MC1658	MC1658P	MC1
Dual 4-Input OR/NOR Gate	MC1660	—	MC1
Quad 2-Input NOR Gate	MC1662	—	MC1
Quad 2-Input OR Gate	MC1664	—	MC1
Dual Clocked RS Flip-Flop	MC1666	—	MC1
Dual Clocked Latch	MC1668	—	MC1
Master Slave Type D Flip-Flop (350 MHz typ)	MC1670	—	MC1
Triple Exclusive-OR Gate	MC1672	—	MC1
Triple Exclusive-NOR Gate	MC1674	—	MC1
Bi-Quinary Counter (350 MHz typ)	MC1678	—	MC1
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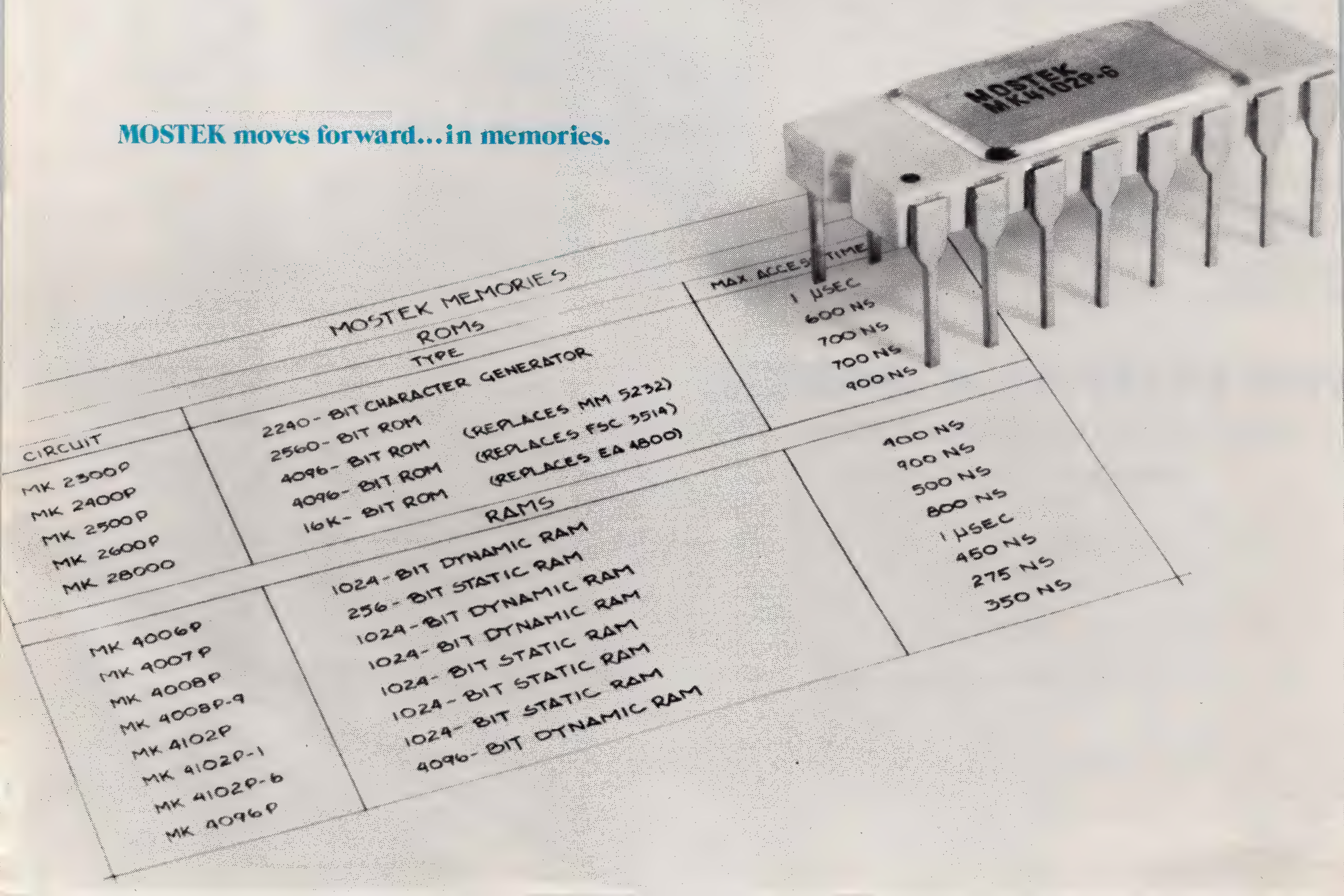
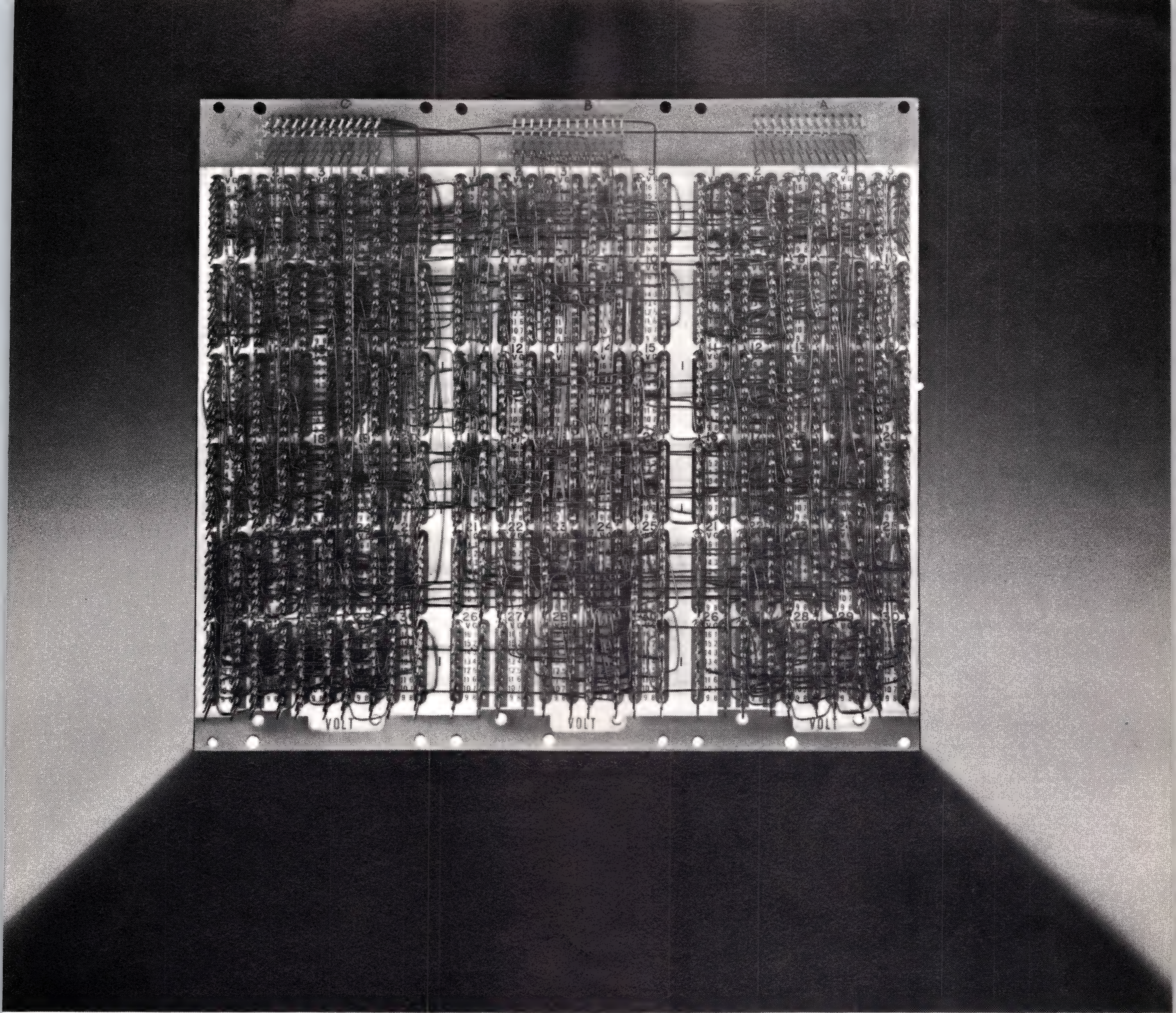


MOSTEK MEMORIES

CIRCUIT	TYPE	MAX. ACCESS TIME
	ROMS	
MK 2300P	2240- BIT CHARACTER GENERATOR	1 µSEC
MK 2400P	2560- BIT ROM	600 NS
MK 2500P	4096- BIT ROM (REPLACES MM 5232)	700 NS
MK 2600P	4096- BIT ROM (REPLACES FSC 3514)	700 NS
MK 28000	16K- BIT ROM (REPLACES EA 4800)	900 NS
	RAMS	
MK 4006P	1024- BIT DYNAMIC RAM	400 NS
MK 4007P	256- BIT STATIC RAM	900 NS
MK 4008P	1024- BIT DYNAMIC RAM	500 NS
MK 4008P-9	1024- BIT DYNAMIC RAM	800 NS
MK 4102P	1024- BIT STATIC RAM	1 µSEC
MK 4102P-1	1024- BIT STATIC RAM	450 NS
MK 4102P-6	1024- BIT STATIC RAM	275 NS
MK 4096P	4096- BIT DYNAMIC RAM	350 NS



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Tape-carrier packaging boasts almost unlimited potential

Now moving from the drawing board into production, this technology provides impressive benefits. Should you be using it?

Walt Patstone, Managing Editor

The tape-carrier microinterconnect system, which has aroused so much interest lately among semiconductor manufacturers for producing DIP IC's, looks like it might have equally great—if not more—potential for hybrid and higher level circuits. In fact, the concept could signal a major change in how electronic packaging will be conducted in the future.

At its core, the tape-carrier concept is deceptively simple. Basically, it boils down to repetitively fabricating miniature printed circuits on a plastic tape that often resembles movie film. From this basic format, the sky's the limit as to what can be accomplished in terms of circuit complexity and processing automation.

Tape (or film) carriers represent essentially a materials handling advancement. But so many opportunities exist for customizing this concept that seldom do any two users see its potential in the same way. Therefore, a great deal of industry secrecy has been created to protect proprietary investigations. To put it in other words, there's more to this story than meets the ear.

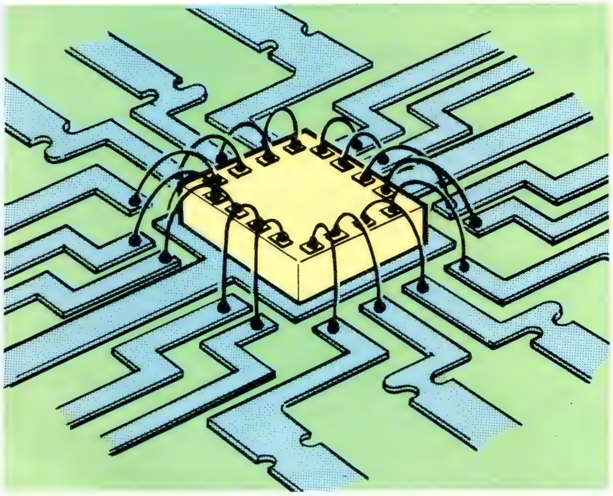


Fig. 1—28 individual bonding operations are needed for the 14 wires in this conventional IC. Typically, the chip is mounted on a lead frame and then connected electrically to the frame with individual wires. Good production personnel can assemble almost 80 of these devices/hr.

Took years to develop

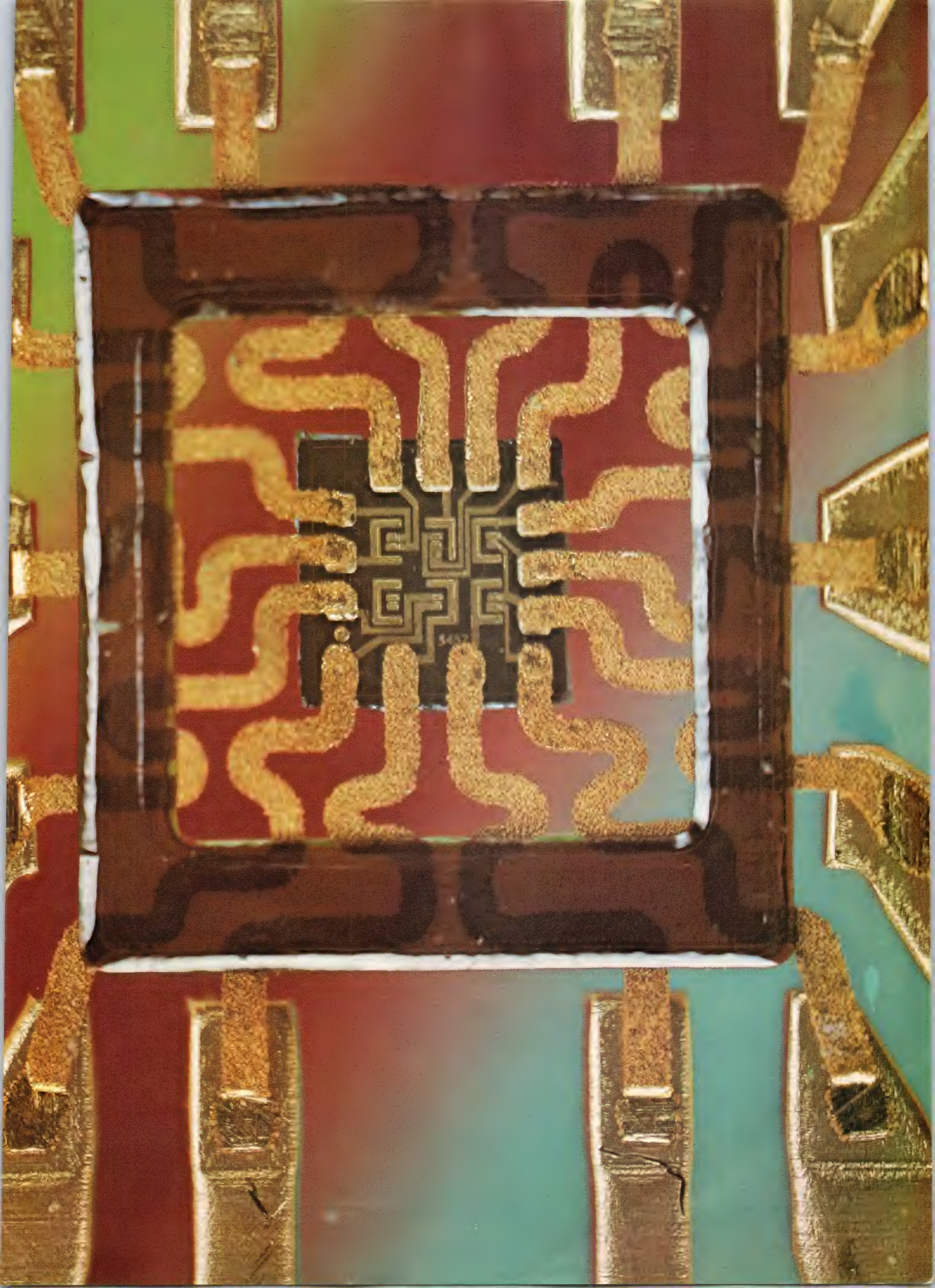
The fact that tape-carrier-based packaging is on the verge of becoming a production breakthrough is evidenced by the stony silence given anyone who attempts to broach the subject with semiconductor manufacturers. Believe me—"mum's the word!" This reticence is all the more significant since the tape-carrier concept really is not new. Both 3M and General Electric pursued the technology in the late 1960's. Each was unaware of the other's activities, though, until GE announced the sale of its line to Texas Instruments in 1971.

In the beginning of the 1970's, technology essentially was shelved, at least by semiconductor houses. Lean sales cut deeply into manufacturing development programs. However, 1973's boom breathed new life into efforts for automating device production...and tape-carrier packaging appears to be right in the middle of things.

Todd Davidson, market manager for tape-carrier technology at 3M, sees four distinct application areas for tape carriers at present:

1. beam-tape DIP's (BT-DIP)
2. beam-tape packages (BTP)
3. beam-tape integrated substrates
4. discrete-device carriers

It only LOOKS like oriental art. Actually it's a close-up photo of a beam-tape IC, showing both inner and outer bonds. In this particular design, a "frame" of film supports the leads.



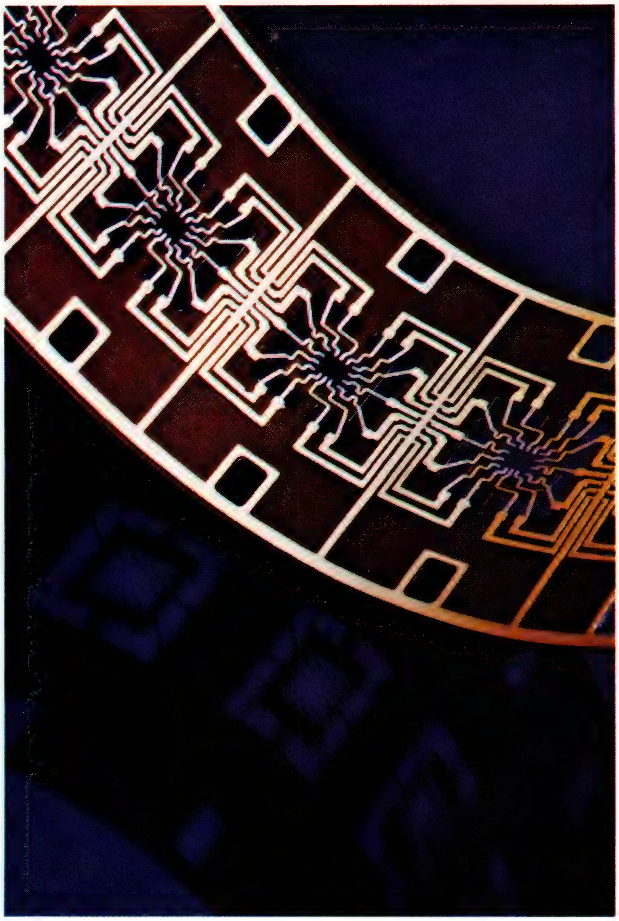


Fig. 2—Close-up of 16 mm IC tape carrier shows miniature laminated copper conductors that are cantilevered free of the film support at both ends. Inside conductors bond to an IC chip; outside conductors bond to a lead frame.

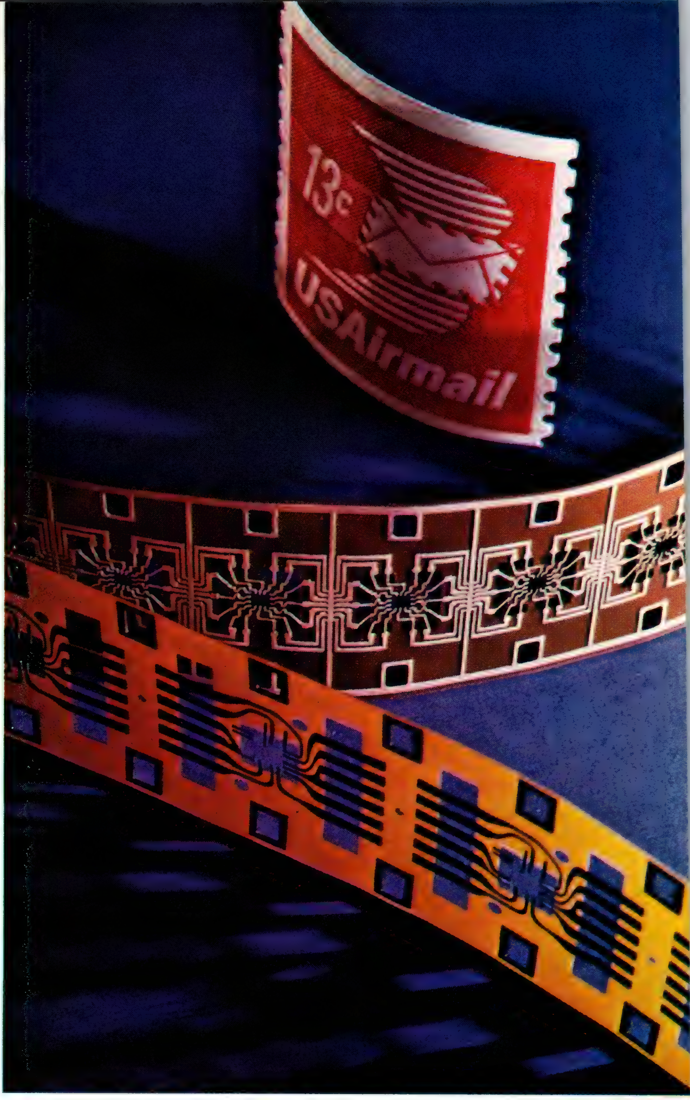


Fig. 3—Transparency of polyimide material is shown by front and bac
ing of these two 16 mm film carriers. Note also the different formats

Fast, fast, fast production

"Right now, materials and equipment suppliers are concentrating their efforts on automating the packaging of dual in-line IC's, using the beam tape technique," Davidson said. "Although no semiconductor manufacturer has announced that he has gone into production of DIP's using the technique, virtually every house has an active development program underway."

Even when IC makers begin using the process, they might not say so. A completed beam-tape DIP looks no different externally from its conventionally wire-bonded brother.

Internally, though, it's a completely different ball game. Instead of the chip being mounted on a metal-lead frame with wire leads individually hand-bonded (two bonds/wire, **Fig. 1**), the beam tape technique permits leads to be bonded simultaneously on automatic equipment. Output/operator can be boosted from about 80 to >1000 devices/hr.

The secret lies in a unique tape carrier, such as the typical design shown in **Figs. 2** and **3**. Modeled after movie film, the tape features miniature laminated metallic conductors that are cantilevered free of the film support at both ends. Those on the inside bond to an IC chip; those on the outside bond to a lead frame.

Fig. 4 illustrates how a typical inner lead bond could be made to chips with raised (or "bumped") terminal pads. Time and labor savings derive from the fact that all the leads are bonded simultaneously, a process referred to as "gang bonding." The bonded chip, supported only by the carrier's cantilevered leads, would appear as in **Fig. 5**. Key to this operation is accurate positioning of the tape's leads on the chip's pads.

The next operation is to make the outer-lead bonds to the lead frame. Here, the inner portion of the plastic film carrier supporting the chip is cropped out (**Fig. 6**), and the outer leads simultaneously bonded to a specially designed lead frame (**Figs. 7** and **8**). The plastic film remains a permanent part of the device, although its function is over at this point. Encapsulation in plastic by conventional molding techniques follows to complete the assembly (**Fig. 9**).

Each semiconductor house has its own approach to this process. Depending upon its investment in automatic transporting, aligning, bonding and testing equipment, a wide range of production rates and changeover capabilities are possible.

Taking some short cuts

An offshoot of the beam-tape DIP is the beam-tape package (BTP). Instead of mounting the platelet with bonded chip (**Fig. 10**) on a DIP lead frame, it is bonded directly to the conductors of a ceramic substrate, flexible printed circuit, or pc board (**Fig. 11**). The IC may be either uninsulated at this point, or preinsulated with a drop of resin as indicated.

Obviously, the BTP should be of great interest to the hybrid and higher level packaging engineer for reasons of size. Also, it short-circuits the need to proceed all the way to a DIP before a usable device is created.

The options are yours

3M's Davidson sees the beam-tape integrated substrate as the logical next step up from the BTP. It would resemble a conventional flexible printed circuit except that IC chips would be bonded directly to it by the inner-lead technique. Outer-lead bonding would be obviated because the cantilevered inner leads for the chips simply would be extensions of the conventional pc conductors.

Depending upon customer desires, the BTP could have plated-through holes and circuitry on both sides. Or it could be cropped into unique shapes or folded in accordian fashion. Any number of possibilities exist for customizing the product.

Although the number of IC's included would be limited by the progressively higher cost of rejects, applications for the concept are nevertheless exciting. For example, some day it would not be surprising to see a $39.95 digital watch incorporating active and passive devices, power source and display all deposited on, or bonded to, a single flexible circuit. Such a device would be assembled entirely by roller-transport, film-carrier techniques, making the low price both feasible and profitable. **Fig. 12** illustrates such an application.

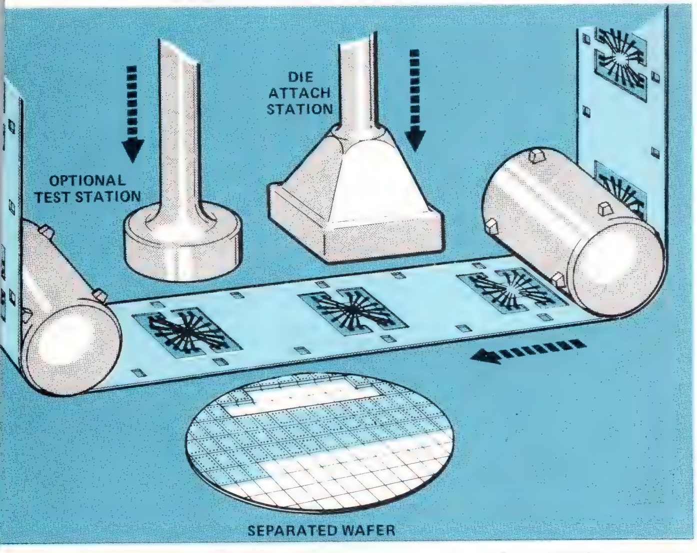


Fig. 4—Inner lead bonding, as shown in this graphical representation, involves removing the IC chip from a wafer array and bonding it to each microinterconnect on a strip of beam tape.

FLEXIBLE COPPER CLAD DIELECTRIC MATERIALS	
X–6600–005	1 oz. copper (1 oz/ft^2 1.4 mils) 1/2 mil polyimide film
X–6680–10	1 oz. copper 1/2 mil epoxy adhesive 3.5 mil polyimide film
X–6670–10	1 oz. copper 1/2 mil polyimide adhesive 2, 3 & 5 mil polyimide film

ETCHING	
1/2 OZ. COPPER	2 mil lines 2 mil spaces
1 OZ. COPPER	3.5 mil lines 3.0 mil spaces,
2 OZ. COPPER	seldom used 5 mil lines 5 mil spaces

PLATING	
GOLD	Soft and pure—thickness 40μ'' (0.04 mils) & up
NICKEL	Thickness 40μ'' & up
COPPER	For plated-thru-holes (PTH)
TIN-LEAD SOLDER	60/40—thickness 200-500μ''
TIN	Immersion— thickness 20-40μ''

CHEMICAL MILLING OF POLYIMIDE FILM	
1/2 MIL	Tolerance ± 1 mil
2.2 MIL	Tolerance ± 3 mils
Punching also available as hole generation method	

The Devil you say

Different in form factor is the folded-tape carrier (FTC) that was the basis of the Texas Instruments' SATAN discrete transistors announced in 1969. **Fig. 13** helps explain the concept.

Basically, copper-clad film tape is processed to form electrically isolated discrete pads that fold under the tape. Devices such as transistor chips (requiring three pads) and LED's (two pads) are mounted on top of one pad, wire-bonded to the adjacent pads, and encapsulated. The end user simply crops out each device and reflow-solders the underside to conductor pads on his substrate. Both manufacturer and user benefit through automatic, roll-to-roll transport processing.

Roll the film

A variety of materials and formats can be supplied for fabricated and etched tape carriers. "Standard movie film type formats include standard 8, super 8, 16, 35 and 70 mm," states 3M's Davidson. "Special formats can be supplied on request.

"The only film-tape material offered to the industry right now is polyimide, a relatively costly but tough and extremely high-temperature-resistant plastic. Amber-colored polyimide can easily withstand the temperatures of thermocompression bonding and reflow soldering," the 3M executive added.

Table 1 describes the range of electrodeposited or rolled copper-clad polyimide tape carriers offered by 3M, along with plating materials, minimum etched line sizes, and chemically-milled hole tolerances. Copper may be clad on one or both sides and may be bonded to the film with epoxy or polyimide adhesives (in order of increasing temperature capability). Alternately, the film may be cast directly to the copper for the ultimate in temperature resistance.

Sprocket and other holes may be formed either by punching or chemical milling (for unusual shapes). Patterning of the circuits (or any special circuit forming) is accomplished by photographic means.

When asked for a design time frame, 3M reported that it takes about six weeks to develop a prototype tape carrier after agreement is reached on what is wanted. This assumes that no special punch tooling is required.

For obvious reasons, Davidson recommends that a tape width as narrow as possible be selected to minimize trim waste.

Got the picture?

The only detailed information available on commercial tape carrier projects concerns the BTP. Specifically, Fairchild pioneered the major work on it and produced two electronic modules for the Polaroid SX-70 Land camera.[1] One module, for exposure control, features four BTP's mounted on a rigid pc board (three of which are shown in **Fig. 14**). The other, a flash-firing assembly, has one BTP mounted to an integrated substrate interconnect—a double-barreled tape-carrier approach (**Fig. 15**).

The most complex BTP on the exposure control module features the bonding of 27 bumps, dissipates an average power of 1.5W, sees a peak power of 2W for 20 msec, and carries a peak current of 1.5A. Fairchild chose a 3M Company 16 mm format, 2-mil thick polyimide film laminated to 1 oz copper (with lead-tin solder) for the BTP carrier. The tape is handled in reels with standoff interleaving for die protection. Encapsulation is in epoxy.

To attach the BTP, the pc board (with tin-lead coated traces) is fluxed and jigged. Then each BTP is located by aligning two holes in the film with holes in the circuit board through which pins have been placed. Attachment is by pulse-tip bonder. Die heatsinking isolates the reflow to the outer lead area.

The flash-firing assembly is similar in construction, except that the integrated substrate is a 70 mm polyimide tape containing a 0.7Ω deposited resistor. This assembly handles up to 2A peak currents and dissipates 3.5W for 50 msec.

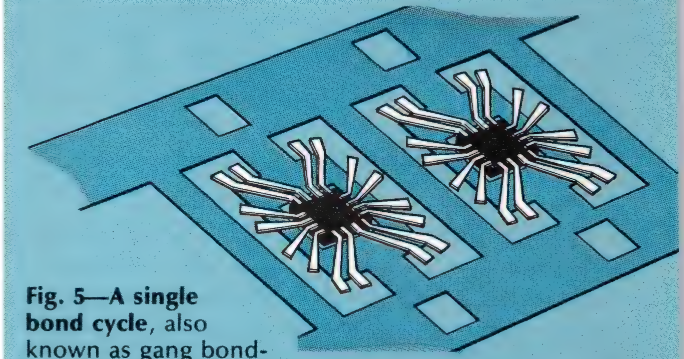


Fig. 5—A single bond cycle, also known as gang bonding, bonds the IC to the microinterconnect. This greatly reduces time and labor in the production process. Howev accurate alignment between bumps on the chip and inner beams on the tape is critical to success of this operation.

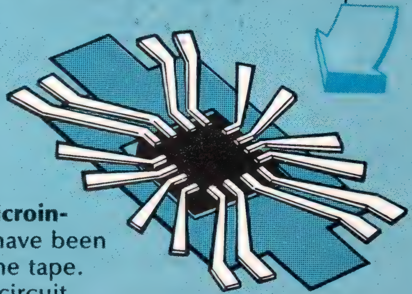


Fig. 6—IC and microinterconnect now have been cropped out of the tape. At this point the circuit could be applied directly to a conventional printed circuit substrate if desired. In such a case, the center portion of the assembly would likely be encapsulated for protection.

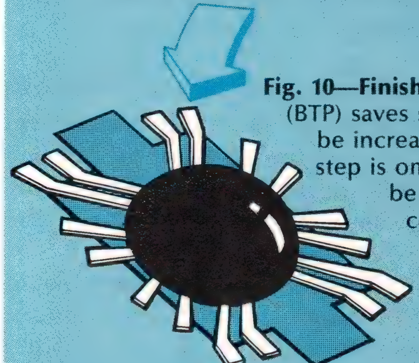


Fig. 10—Finished beam-tape package (BTP) saves space. Yield also might be increased, since an assembly step is omitted. Device now can be bonded directly to the conductors of a ceramic substrated, flexible printed circuit, or pc board (**Fig. 11**).

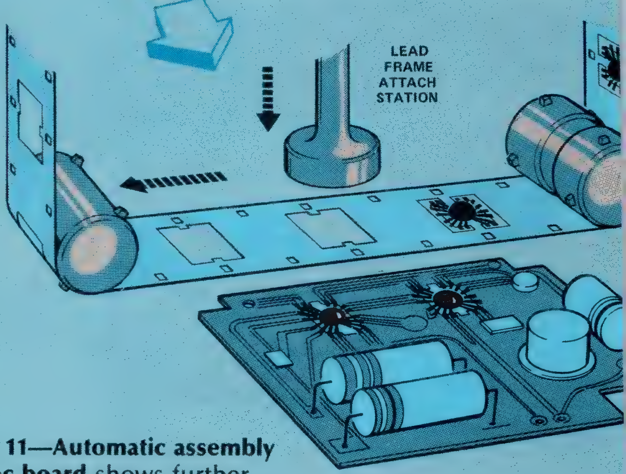


Fig. 11—Automatic assembly of pc board shows further cost savings of beam-tape technology. The tape of BTP's is fed through a bonder which crops them out and attaches (gang bonds) them directly to the printed-circuit board.

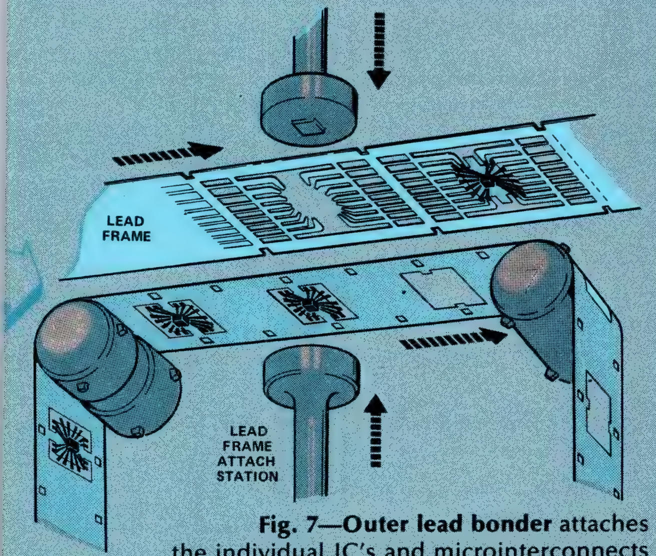


Fig. 7—Outer lead bonder attaches the individual IC's and microinterconnects to lead frames in a single bonding operation.

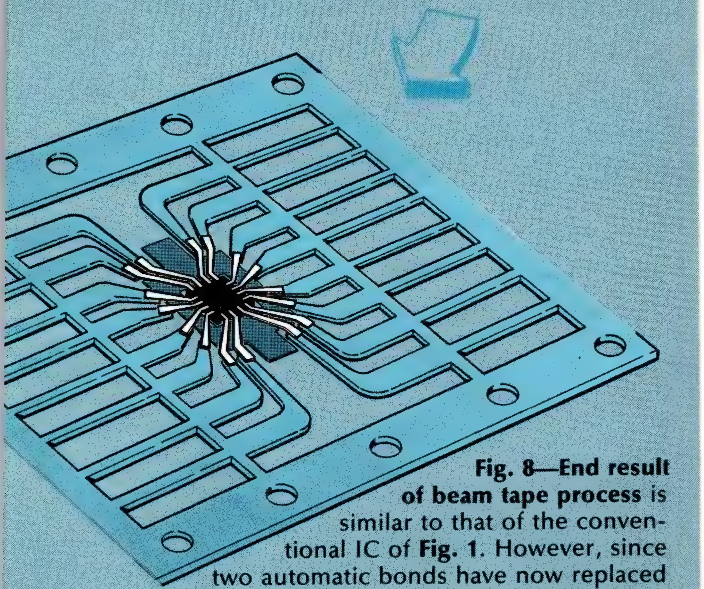


Fig. 8—End result of beam tape process is similar to that of the conventional IC of **Fig. 1**. However, since two automatic bonds have now replaced 28 hand operations, production rate has dramatically increased (to >1000 devices/hr), while costs have significantly decreased.

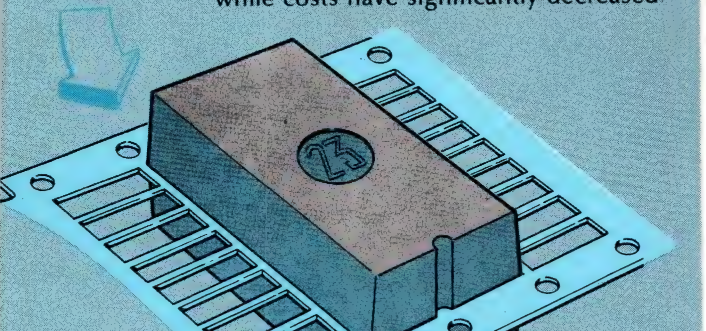


Fig. 9—Who knew? Inside the finished molded package is an IC assembled using beam-tape technology. Yet externally it is identical to a conventional plastic DIP.

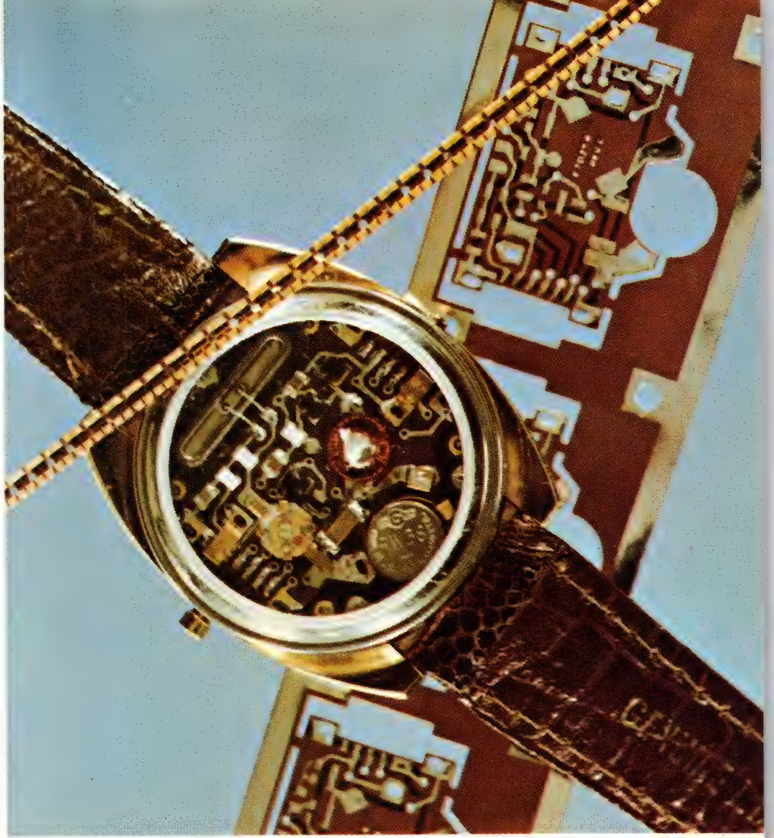


Fig. 12—Now is the time for many consumer and computer applications to incorporate beam-tape technology. Circuit substrate in this watch is formed by discrete-device-carrier process. Beneath watch is the carrier upon which the electronic components were mounted. Thin strip in the foreground is folded-tape carrier for manufacturing discrete transistors.

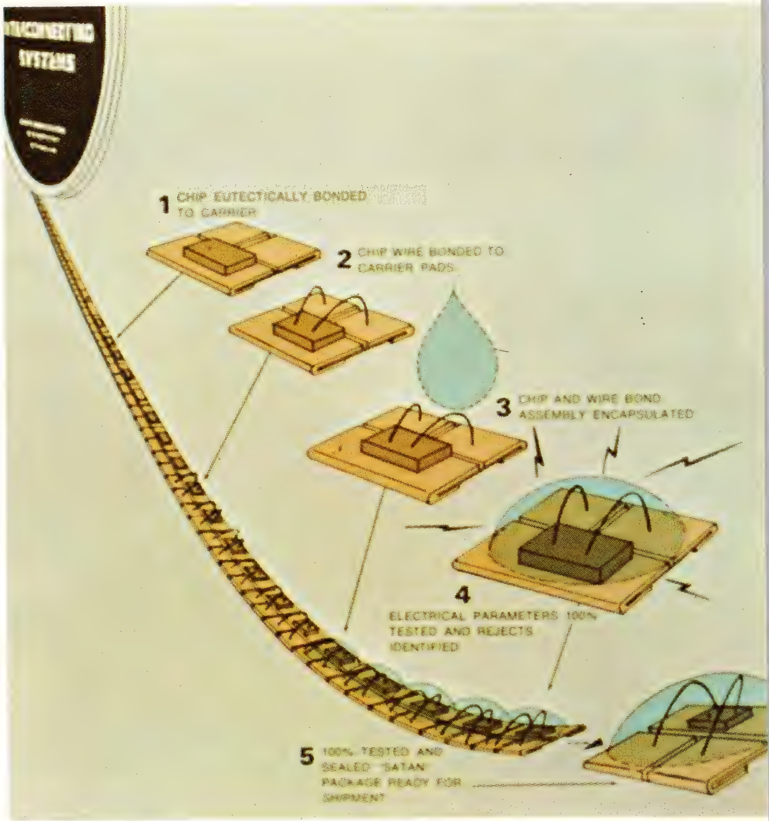

SYSTEMS
1 CHIP EUTECTICALLY BONDED TO CARRIER
2 CHIP WIRE BONDED TO CARRIER PADS
3 CHIP AND WIRE BOND ASSEMBLY ENCAPSULATED
4 ELECTRICAL PARAMETERS 100% TESTED AND REJECTS IDENTIFIED
5 100% TESTED AND SEALED "SATAN" PACKAGE READY FOR SHIPMENT

Fig. 13—Discrete transistors and LED's are packaged by the folded-tape carrier technique. This was the basis of Texas Instrument's SATAN transistor line announced in 1969. End user simply crops out each device and reflow solders the underside to conductor pads on his substrate.

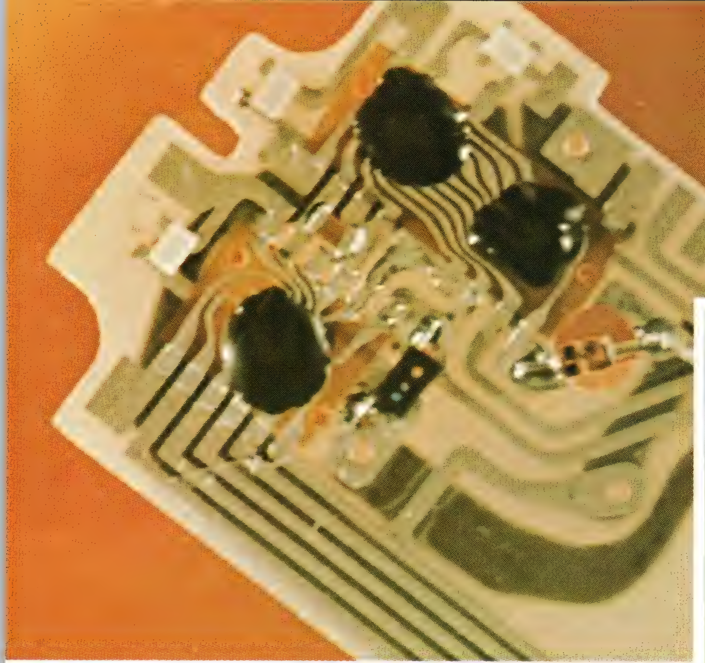


Fig. 14—Smile! Three beam-tape packages, with their chips encapsulated in black epoxy, are mounted on pc board to form the exposure control module of Polaroid SX-70 Land Camera. Fairchild Camera and Instrument Co. performed major pioneering work on BTP's.

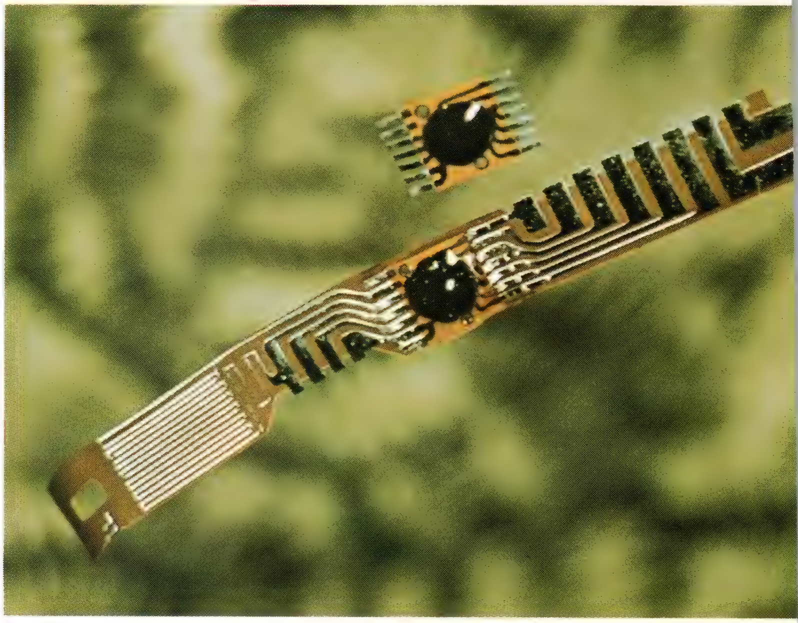


Fig. 15—Flash!! Single BTP for flash firing assembly of SX-70 camera mounts on an integrated substrate interconnect featuring a deposited resistor and formed from a wide, 70 mm tape. Note tape's sprocket holes on either end of the substrate. These are used in mounting the assembly within the camera. Circuit handles up to 2A peak currents and dissipates 3.5W for 50 msec.

The other major BTP investigator of public record is Societe Honeywell Bull in France.[2] This firm has developed means and equipment for making the inner-lead chip bond and for attaching the BTP to a multi-layer ceramic substrate. Reported advantages are high density mounting for more compact and faster computers.

Getting into the technology

Conversations with materials and equipment suppliers, as well as with present investigators, provide the following insights for those considering use of the tape-carrier technology.

First, the technique is primarily one for high-volume production, at least at this point in time. The substantial investment in time and money can only be recouped satisfactorily in relatively high unit production.

Second, no off-the-shelf materials or equipment exists now. Although materials and equipment are quite highly developed, they are still custom designed. The burden is primarily on the end-user to research the technology.

Third, several of those interviewed recommended that the film-carrier technique be considered as part of a total manufacturing system advancement involving a range of complementary efforts. The savings from a simple part-for-part replacement may not justify the investment.

Last, this technology should be approached in an evolutionary manner—sort of a "walk before you run" approach. Even the largest and best-financed investigators have tended to take the technology slowly from the simple to the more complex, making sure they are confident in what they are presently doing before advancing to the next step.

As stated by Hugh Harris, technical sales director for the Jade Corporation, a leading supplier of bonding equipment: "There is no particular problem to making the tape-carrier system work in the lab. However, it takes thorough process development and well-thought-out equipment to obtain high yields in high volume on the production line."

What about the future?

Tape-carrier packaging technology looks extremely promising as a means of reducing the manufacturing costs of mass-produced electronic equipment and components. Two areas will stand out in the near future: consumer products and computers.

For consumers, it is not difficult to envision tape-carrier technology being applied to the manufacture of electronic watches and clocks, calculators, hearing aids, automatic cameras, automotive electronics, miniature radios, recorders, and, perhaps, to special solutions for TV's and other appliances.

Some experts have asserted that tape-carrier technology has little to offer computer people in light of the industry's great investment in, and experience with, the multiple-sourced DIP. But others say just the opposite, believing that computer-oriented applications could overshadow consumer goods. We will have to wait and see which side is correct.

One thing is certain, however—the beam-tape packaging technique appears to be a logical alternative to the beam-lead hybrid packaging method pioneered by Bell Labs and Western Electric.

"The BTP has a clear advantage over the beam-lead approach because special process and product development is not required," stated Dr. Thomas Longo, vice president and general manager, Integrated Circuits group, Fairchild. "Changes in the design of devices can be accomplished relatively quickly and easily."

Longo sees the BTP device especially useful for digital SSI and MSI circuits, and for linear circuits such as op amps. He believes the economic advantages lie with the less complex IC's, where the cost of packaging takes a proportionately larger share of total device cost.

Yet, as the number of leads increase, the advantages of the BTP's simultaneous bonding grows. 3M states that the number of inner lead bonds doesn't seem to be a limiting factor—they have designed tape carriers for IC's with as many as 40 leads. Honeywell reports bonding up to 72 leads.

Longo also commented that he is encouraging the military to go BTP. One military program is on the verge of converting from beam-lead to beam-tape packaging, according to the Fairchild executive.

Closing on a minor (?) point

What about the availability of IC chips for companies that may want to do their own BTP hybrid and higher level packaging work?

"I believe the day will come when Fairchild will be supplying reels of tape carriers with inner-lead-bonded chips," Dr. Longo asserted. However, when asked whether his company would be willing to supply bumped chips alone, Longo said he would not encourage their marketing in this form. Problems of quality control and quality responsibility were cited as reasons. □

References

1. *"Beam and Beamless Tape Packaging," Frank A. Perrino, Proceedings of the 11th IEEE - NEMA Electrical Insulation Circuit Conference, 1973.*

2. *"Tape Automated Bonding, a New Multichip Module Assembly Technique," Proceedings of the 23rd IEEE-EIA Electronic Components Conference, 1973.*

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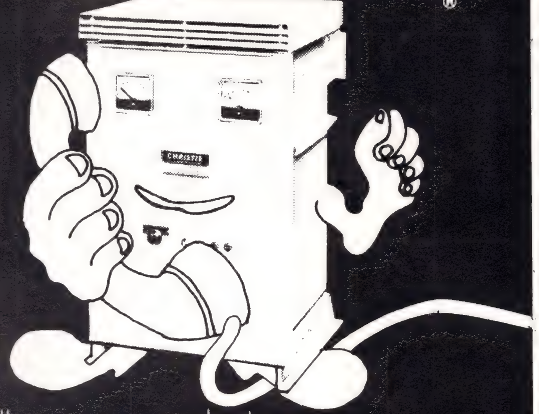

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conversation piece

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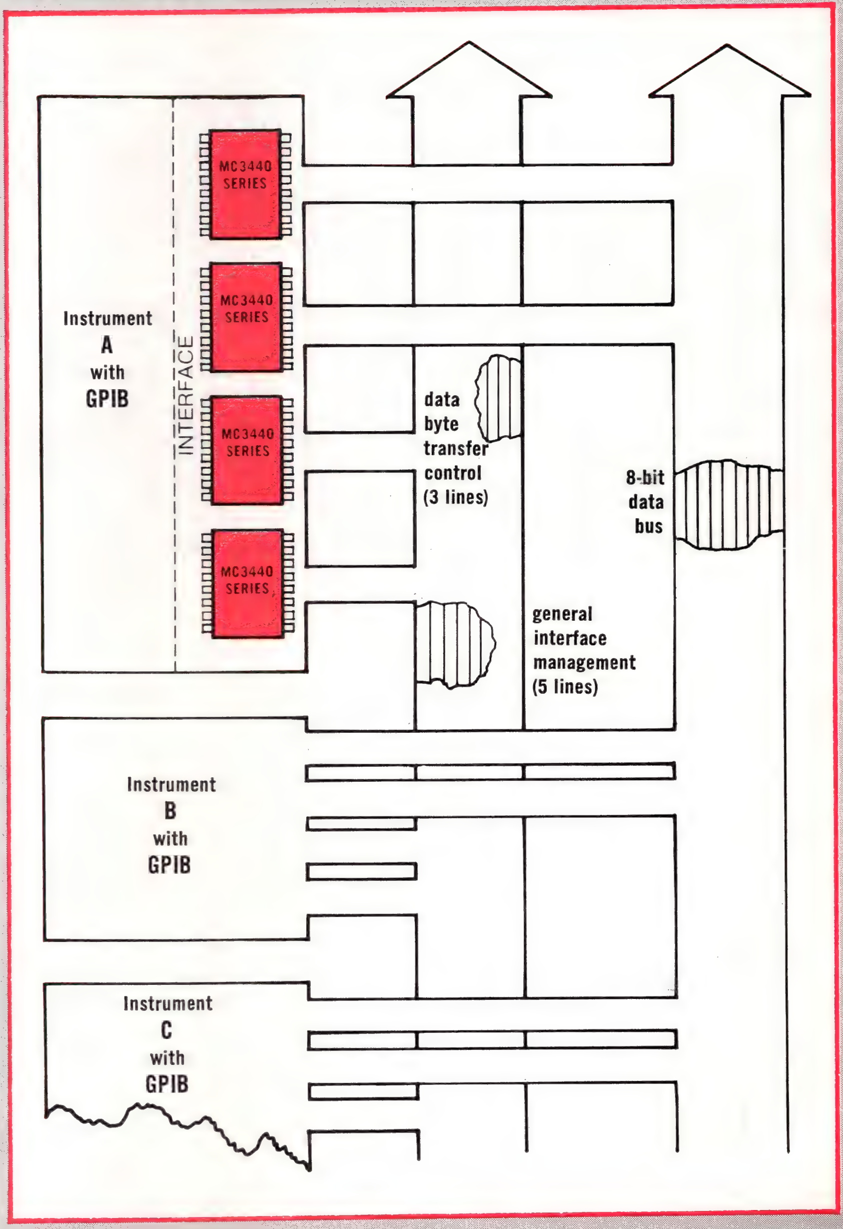

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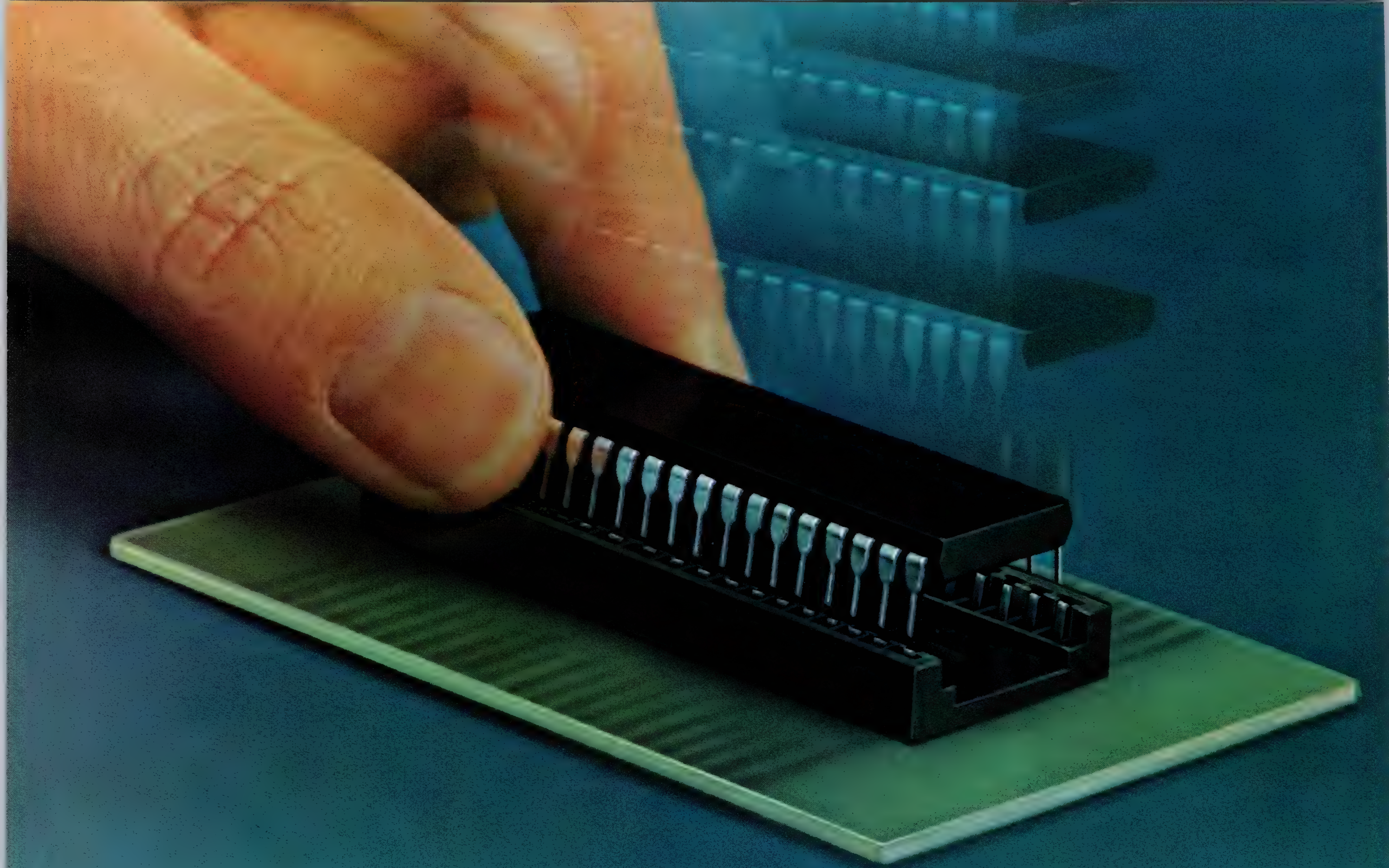

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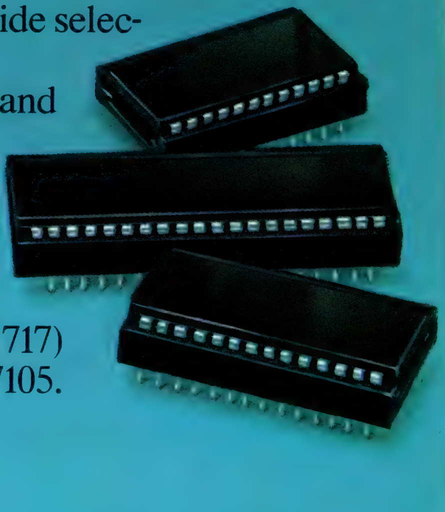

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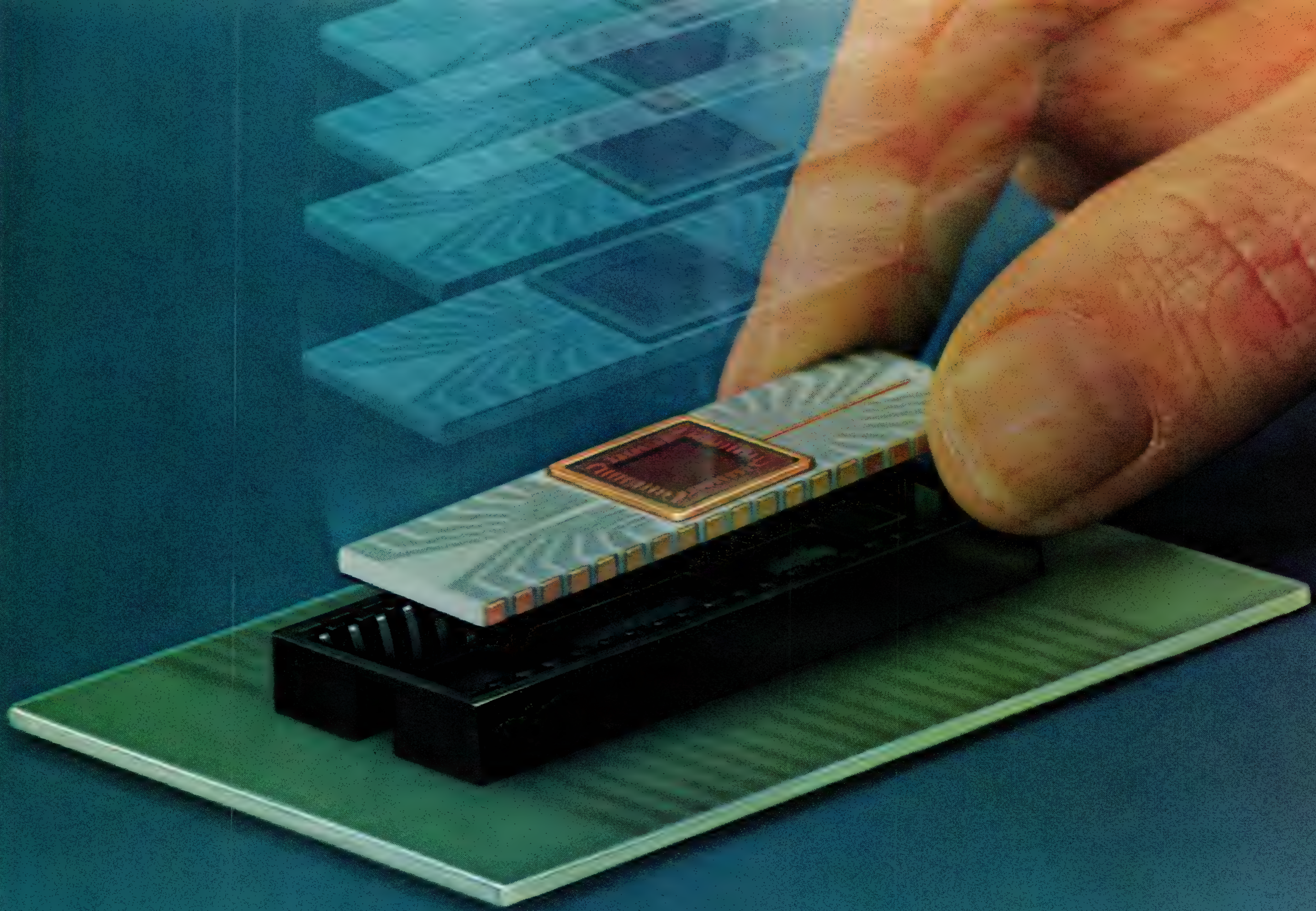

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Contest winners apply A/D's and D/A's in novel and useful ways

Data converters are committed devices that have been around a long time. Are there still new applications to conquer? Certainly!

Robert Jay, Micro Networks Corp.

Micro Networks sponsored its design contest to spark new interest in the application of data converters. Rules and judging criteria were simple: Applications must have included one or more A/D and/or D/A converters (not necessarily Micro Networks' products), and judgment was to be based on originality, practical value and completeness.

The contest was eminently successful. Running it was both an enjoyable and a challenging experience. Entries showed great thought and imagination, making judging difficult. In the end, however, Bill E. Dozer earned the grand prize—a $1000 U.S. Savings Bond. Eight other very deserving designers received runner-up prizes.

To the winners, we offer our congratulations. To all who entered, we express our sincere appreciation. To you, EDN's audience, we present the top four design ideas as food for thought and inspiration.

MICRO NETWORKS' "GRAND CONTEST" WINNERS

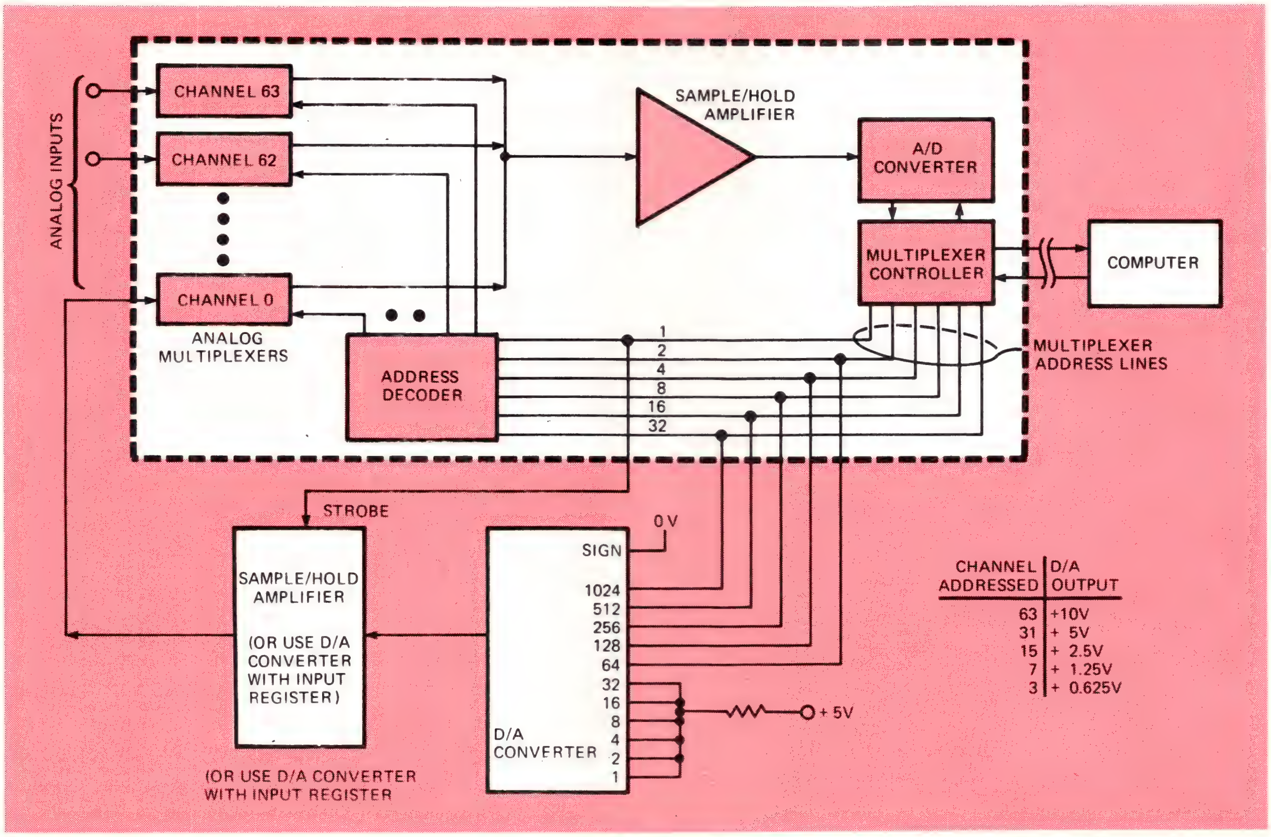
PLACE	WINNER	DESIGN IDEA	PRIZE
1	BILL E. DOZER, RICHLAND, WA	PROGRAMMABLE SIGNAL CALIBRATES REMOTE ANALOG MUX	$1000 BOND
2	JULIUS CSAKI, COLORADO SPRINGS, CO	SYSTEM AUTOMATICALLY CONVERTS CRT CATHODES	MINI-CALCULATOR
3	KINGSLEY P. ROBY, DANBURY, CT	TRANSIENT SIGNAL ANALYZER HAS MULTIPLE USES	"
4	B.W. GLASS, ANNANDALE, VA	PROVIDE AUTOMATIC CALIBRATION FOR MULTICHANNEL SIGNAL-CONDITIONING SYSTEMS	"
5	WILLIAM R. BECK, AUSTIN, MN	DIGITAL CONTROL FOR A MASS SPECTROMETER	"
6	NORMAN W. PERRY, PROVO, UT	AUTOMATIC STRIP-CHART & RECORDER SCALE EXPANDER	"
7	STEPHEN E. GRANT, LEE'S SUMMIT, MO	10-BIT SAMPLE/HOLD OR PEAK/HOLD CONVERTER	"
8	JACK ADAMS AND ROBERT WEYANT, POMONA, CA	TONE RECORDER/SYNTHESIZER	"
9	J.F. SUTTON, BELTSVILLE, MD	PHASE—LOCKED—LOOP SWEEP GENERATOR	"

Programmable signal calibrates a remote analog MUX

Bill E. Dozer

Many analog input data acquisition systems utilize analog multiplexers located some distance from the central control computer. This is generally done to save wiring costs between the multiplexer and computer. Frequently the data transmission is in serial form, consisting of a multiplexer channel address in one direction and converted digital data returned. While this system works well, about the only method of checking the calibration of the analog multiplexer-A/D combination is with a precision power supply that provides preset voltages connected to several dedicated analog multiplexer channels. This is costly, unduly complicated and wastes multiplexer input channels.

In this solution, the multiplexer binary channel address lines are connected to a D/A converter that in turn is connected to channel zero of the multiplexer. Since most multiplexers of this type utilize random addressing, the computer can send any predetermined address to the multiplexer. This sets the D/A converter to a predetermined voltage level and strobes that value into the converter. The computer then addresses channel zero, receives the data back, and checks to determine if the system calibration is correct. This can be done at different values and polarities to check linearity, accuracy, etc. The dummy channel addresses do not affect the true channels with the same address since they can still be addressed correctly and the output of channel zero ignored.



CHANNEL ADDRESSED	D/A OUTPUT
63	+10V
31	+ 5V
15	+ 2.5V
7	+ 1.25V
3	+ 0.625V

Any odd-numbered channel address strobes in a calibration voltage to check the analog multiplexer-A/D combination. System is simple, efficient and flexible

In the example shown, a 12-bit, ±10V D/A converter was connected to a 64 channel multiplexer (six address bits). Five of the six bits were used to code five different calibration voltages, while the sixth one strobed the data into the D/A converter. Either a sample/hold amplifier or a D/A converter with an input register will be necessary to hold the value while channel zero is addressed to obtain the calibration check. Any odd-numbered channel address strobes in a calibration voltage. Thus, 32 combinations are possible in this case. Other voltage combinations could be obtained by using different D/A bits or the sign bit. ☐

System automatically converts CRT cathodes

Julius Csaki

Several cathode conversion techniques have been used in the production of CRT's with varying degrees of success. One such procedure followed a fixed schedule in which the filament voltages were taken from approximately 25% of hotshot voltage to 100% of it, through several discrete voltage steps. The quality of manifold vacuum was not considered in the schedule. As a result, CRT cathodes were converted at various pressures, depending on the amount of outgassing in individual tubes. Conversion at excessive pressures was found to be detrimental to cathode life and performance, so a new technique was needed.

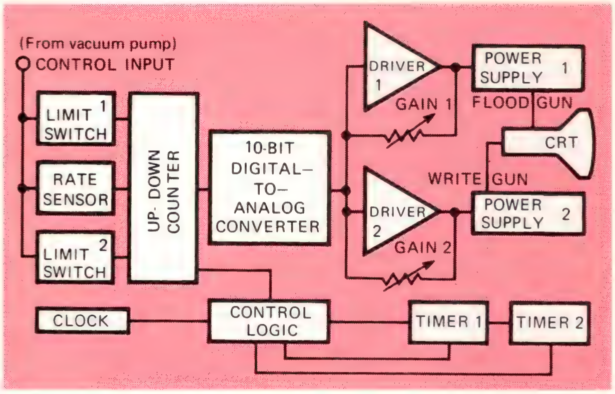
This system performs automatic conversion. It uses a control signal from the vacuum pump to ensure that cathode conversion takes place under a much better and nearly constant vacuum.

The "gain 1" and "gain 2" controls select any one of several programs according to the filament types used in the CRT. (In the following description, hotshot voltage—E_{hs}—is a reference.)

At the start of the cycle the system applies 0.25 E_{hs} to filaments. Pushing the START switch enables the counters to start up-counting. This binary count converts to an analog voltage in the 10-bit DAC. The DAC's output is then applied to the individual drivers that remote-program the output power supplies. Remote sensing reduces the degradation of regulation that would occur due to the voltage drop in the leads between the power supplies and the loads.

As long as the control voltage (which is linearly proportional to the vacuum in the system) does not exceed the preset limit, the counters will fill up in about 4 min., 35 sec. During this time the linear voltage ramp reaches E_{hs}. Timer 1 then disables the clock and allows E_{hs} to be applied to the CRT. When timer 1 times out (approx. 35 sec), it triggers timer 2 and through the control logic sets the counters to 0.75 E_{hs}. This voltage is applied to the CRT filaments for 12 minutes. At the end of this period, the RTT light comes on, indicating that the tube is ready to be tipped off. When the tube is sealed, the conversion system is shut off by pressing the STOP switch.

It should quickly be noted, however, that such ideal circumstances seldom occur. Due to outgassing in the CRT during cathode conversion, considerable pressure changes are encountered in the vacuum pump manifold. To ensure that the cathodes are converted while holding a relatively constant high vacuum in the CRT, the following events are programmed.



Better and more consistent cathode conversion, and thus better and more reliable CRT's, are products of this automatic system. Careful attention has been paid to the handling of potential problem situations.

Whenever the control input reaches the tripping voltage of limit switch 1, the up-count stops, holding the previously achieved voltage at the CRT filaments. Due to the time lag between the pressure change in the CRT and in the vacuum pump (feedback point), the pressure may still continue to rise until it triggers limit switch 2. This, in turn, commands the counters to start down-counting, thereby starting a down-ramp of voltage at the CRT filaments.

The vacuum pump now should be able to overcome the outgassing action in the tube and the control input deactivates limit switch 2 to stop the down-count. Further improvement in vacuum deactivates limit switch 1, whereby the counters start the up-count again. This process is repeated until E_{hs} is reached. When a very rapid rate of change takes place at the control input, the "rate sensor" changes states, stopping the up-count even before the tripping voltage for limit switch 1 is reached.

Application of this automatic system will hopefully yield more consistent and better cathode conversion than that of previously used methods. Test results have shown the method to work quite well for several different CRT types and on several different vacuum systems. The time required for a complete conversion cycle may be somewhat longer than the fixed schedules previously used, but the improved levels of cathode performance obtained seem to justify its use. □

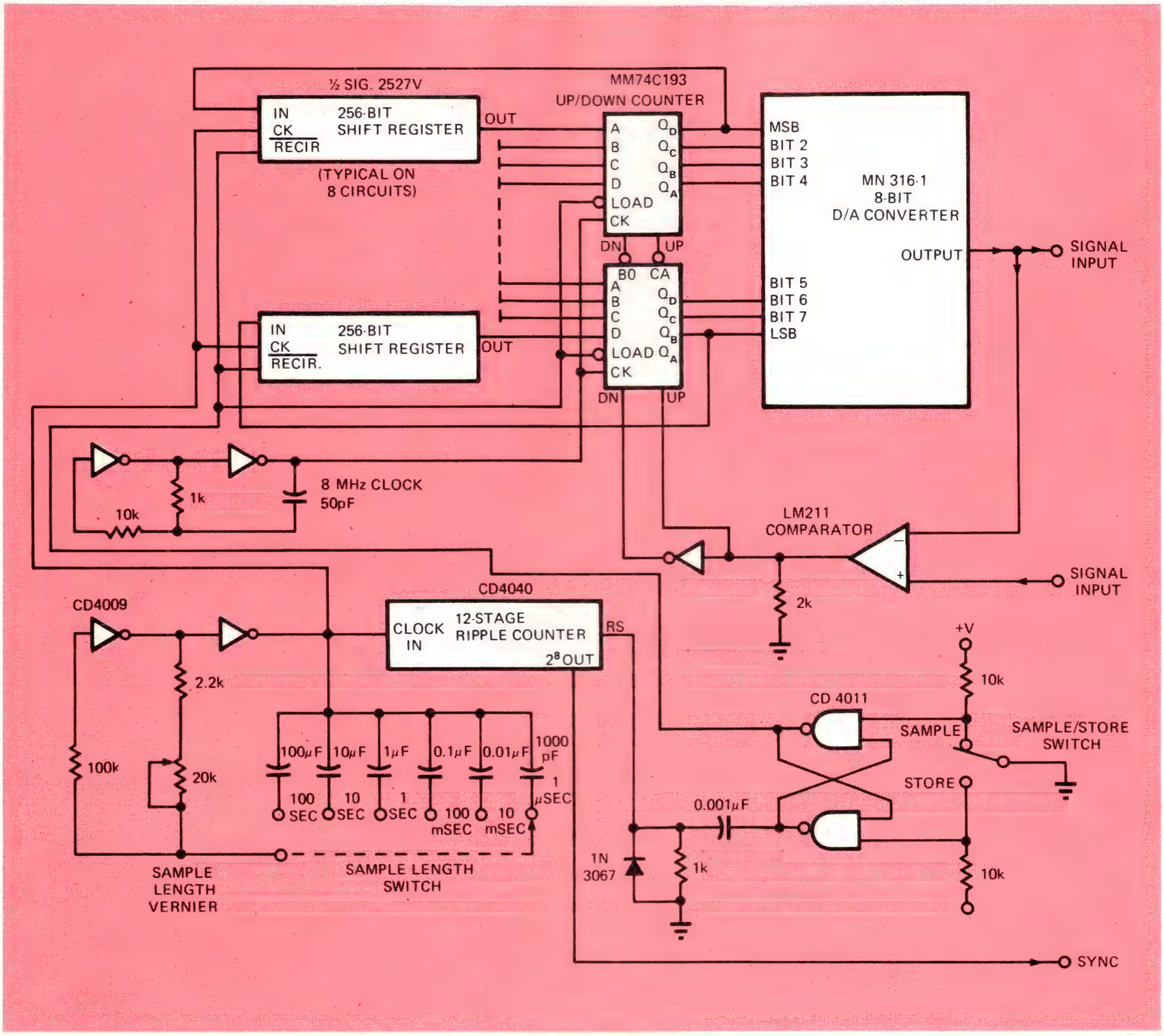
Transient signal analyzer has multiple uses

K. P. Roby

This circuit may be used as a low-cost substitute for a storage-type oscilloscope. It is useful for studying analog variables in the area of speech synthesis, biological signal analysis and destructive testing of components. It may also be used to save paper with chart recorders.

Basically it is a tracking A/D converter whose digital output is fed into a 256- × 8-bit shift register. In an alternate mode, the shift register's contents are recirculated into the inputs of a D/A converter, and a previously-stored signal segment is cycled for evaluation at the D/A output.

Sample Mode—When the sample/store switch lies in the SAMPLE position, the circuit is configured to allow the MM74C193 up/down counters to count according to the up and down



Transient signal analysis, time compression and analog simulation can all be accomplished by this circuit. In the SAMPLE mode, it's basically a tracking A/D whose output is fed into a 256- × 8-bit shift register. In the STORE mode, the signal output repeats the last 256 digitized samples taken during the SAMPLE mode.

count-enable inputs. The 256-bit shift registers are configured to accept input data. Applied to the noninverting input of the LM211 comparator is the input signal; the output of the MN316-1 D/A converter is applied to the inverting input.

The comparator's output controls the up or down counting of the up/down counter. It will count in the direction that reduces the difference of the D/A output and the signal input. Consequently, the D/A converter tracks the input signal as long as the input's slew rate does not exceed 5 V/μsec.

Output of the up/down counter also drives the inputs of the 256- × 8-bit shift register. This data is clocked into the shift register and represents a series of digitized samples of the signal input.

The clock for the shift register is not synchronous with the up/down counter clock. Rather, it is generated by a separate clock generator based on an appropriate sample period. This clock is continuously adjustable from about 250 kHz to about 4 sec/cycle. Its output is fed to a 12-stage ripple counter. The 2^8 (256) output of the ripple counter is used as a reference output, providing one transition for each complete rotation of the shift register contents.

A clock rate of 250 kHz would provide a sample period of about 1 msec. That is, the shift register could store the input signal for a 1-msec interval. Storage is allowed for intervals from 1 msec minimum to approximately 1000 seconds max.

Store Mode—When the SAMPLE/STORE switch is changed to the STORE position, a reset pulse causes the SYNC pulse counter to jump to the beginning of the cycle. This, in turn, causes the sync transition to appear synchronously with the point in time that the switch was placed in the store mode. Additionally, the shift registers are placed in the recirculate mode. Thus, no new data enters the shift register and the last 256 bits continue to rotate through it. This provides a sequence of 8-bit digital samples to the parallel inputs of the up/down counters. Since the load inputs are enabled, these eight bits are forced to the counter's outputs and then directly to the inputs of the D/A converter. Consequently, in the STORE mode, the D/A's output repeats the successive digitized samples of the last 256-bit interval during the SAMPLE mode.

Circuit Uses—The most significant applications for this circuit include the following:

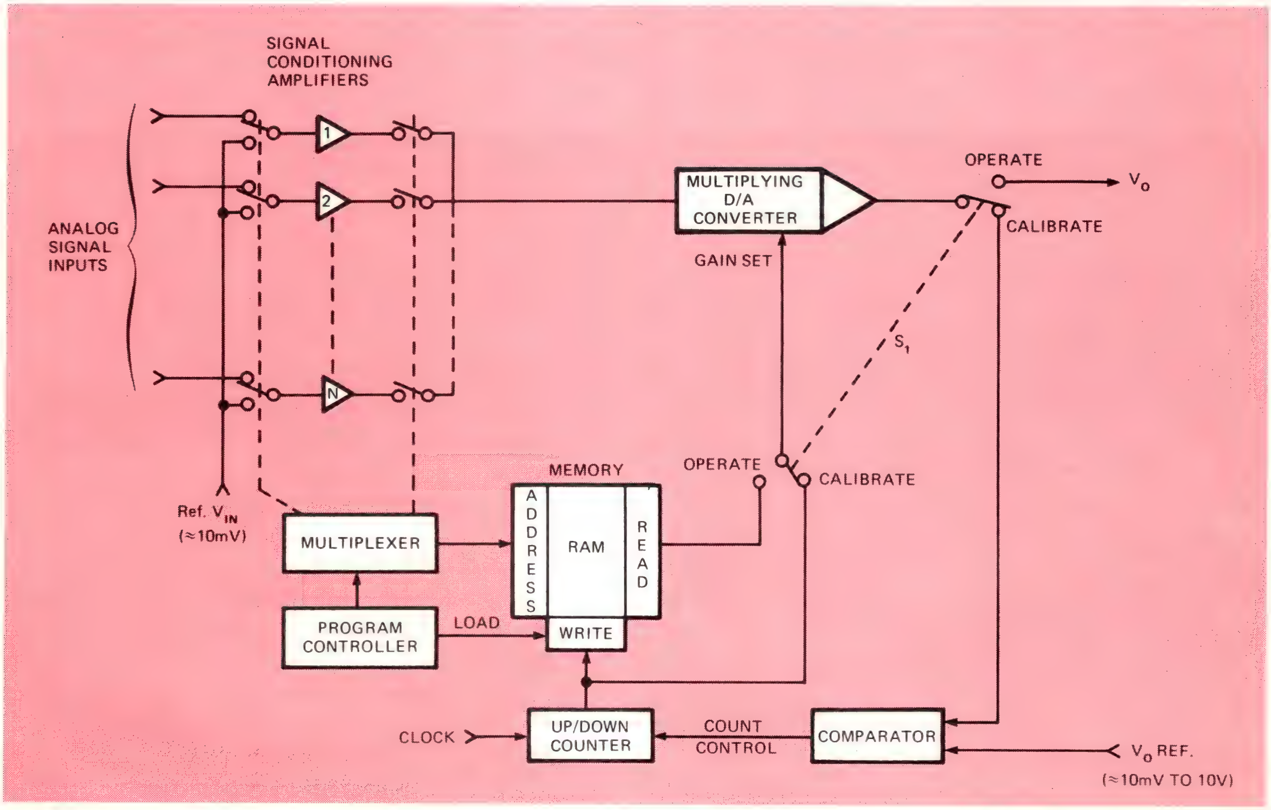
1. Transient Signal Analysis—It's possible to capture a segment of a nonrepetitive analog signal and then repeat it for use as an oscilloscope display for careful examination.
2. Time Compression—It's possible to record a slowly varying analog signal in the SAMPLE mode and then increase the clock rate in the STORE mode. This allows a legible scope presentation.
3. Analog Simulation—By setting a fairly long sample period and providing a variable dc input in the SAMPLE mode, an operator can program a single sample period with an arbitrary analog signal. At the end of the scan, the circuit is switched into the STORE mode and the signal may then be played back at any repetition rate. □

Automatic calibration for multichannel signal conditioning systems

B. W. Glass

The block diagram shows a system in which a multiplying D/A converter automatically sets (calibrates) the gains of a multichannel data acquisition system. Gains of the individual signal-conditioning amplifiers need not be separately calibrated.

In the calibrate mode, S_1 is in the position shown, and the program controller instructs the



Individual signal conditioning amplifiers need not be adjusted separately because multiplying D/A is programmed by calibrate system to compensate for errors.

multiplexer to:

1. Connect the input of a signal conditioning amplifier to a reference input voltage.
2. Connect the output of the same amplifier to the normal reference input of the D/A ladder network.
3. Address a word storage position in the random access memory.

The comparator then compares the D/A output with the output reference (V_0 REF) and directs the up/down counter to select the digital word that causes the D/A's output to be the same as V_0 REF.

Gain for this channel will then be:

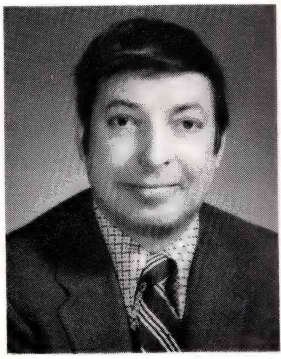
$$G = \frac{V_0\,REF}{V_{IN}REF}$$

When this condition is reached, the controller loads the digital word value into the memory position determined by the multiplexer-supplied address. It then selects the next amplifier and the calibration process is repeated.

In the operate mode, whenever the multiplexer selects a channel, the corresponding gain value is read from memory to the D/A and sets the gain accordingly.

If channel gains are required to be individually different, this system can be expanded so that another D/A is addressed during calibration to supply V_0 REF. Gain is still set by the above equation. □

Author's biography



Robert Jay is the president and the founder (5 yrs. ago) of Micro Networks Corp., in Worcester, MA. He received his B.S. in engineering at Notre Dame and his MBA, with distinction, from Harvard Business School. Quite justifiably so, Bob is extremely proud of his company's new building. About this article and the market he serves, Bob says, "Rapid advances in D/A and A/D technology have resulted in converters that are convenient to handle while offering improved performance. Yet simultaneously prices have declined to levels which now open up entire new areas for data acquisition control and instrumentation."

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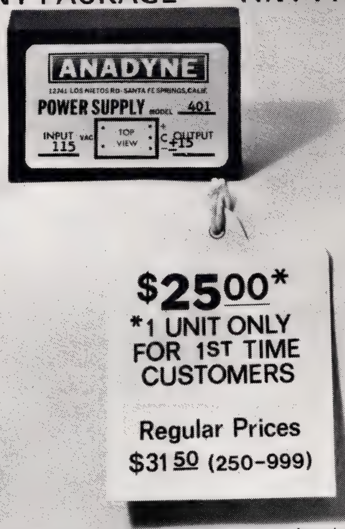

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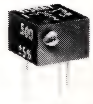
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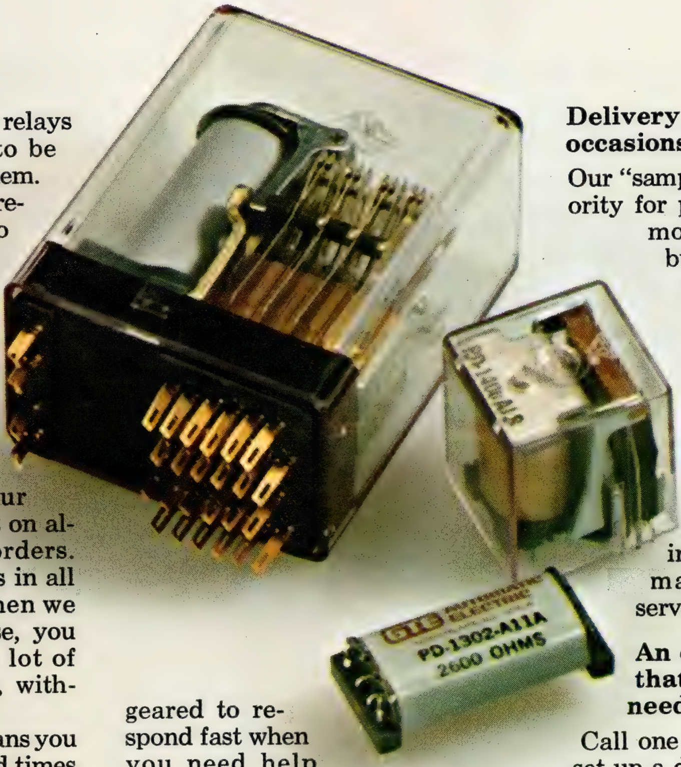

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Designers' Guide to: Switching regulators, Part 1

By going to a fixed-off-time mode regulator, you can overcome some of the design constraints imposed by earlier switching regulators.

Lloyd Dixon and **Raoji Patel**, Unitrode Corp.

If you need high efficiency under all input and output conditions and good regulation despite large changes in input voltage, you should consider the switching regulator.

Unlike conventional "dissipative" series or shunt regulators, where the power-regulating transistor operates in a continuous-conduction mode, the switching regulator operates by varying the ON-OFF duty cycle of the power transistor switch. Since you can make the switching frequency much higher than the line frequency, filtering elements can be small, lightweight, low in cost and very efficient. You can also drive the switching regulator with poorly filtered dc, thereby eliminating large and expensive line-frequency filtering elements. In fact, in high-power applications, 3-phase rectification without filtering of any kind is often used to develop the input dc from the power line.

Finally, you can design switching regulators with excellent load-transient properties. In a good switching regulator, step increases of load current cause relatively small instantaneous changes in output voltage. And recovery is completed in a few hundred microseconds.

Noise & response-time considerations

The switching regulator does have disadvantages that preclude its use in some applications. The primary power source delivers current to the switching regulator in pulses that, for efficiency reasons, have short rise and fall times. In those applications where a significant series impedance appears between the supply and the regulator, the rapid changes in current can generate considerable noise. This problem can be minimized by reducing the series impedance, increasing the switching time, or filtering the input to the regulator.

A second problem of the switching regulator, compared to the dissipative regulator, is its response time to rapid changes in load current. The switching regulator will reach a new equilibrium only when the average inductor current reaches its new steady-state value. In order to make this time short, you should use low inductor values, or design for a large difference between the input and output voltage.

Basic switching-regulator configuration

The basic switching regulator shown in **Fig. 1** accepts a dc input voltage and regulates a dc output voltage, despite variations in E_{in} and load current. Static regulation, dynamic regulation, and ripple rejection of this type of regulator cannot be as easily optimized as they can in a continuous "dissipative" series regulator. However, the switching regulator's efficiency, power density (watts output/cubic inch) and economy are all markedly superior to the series regulator—particularly for a high-current one with a large input-to-output voltage difference.

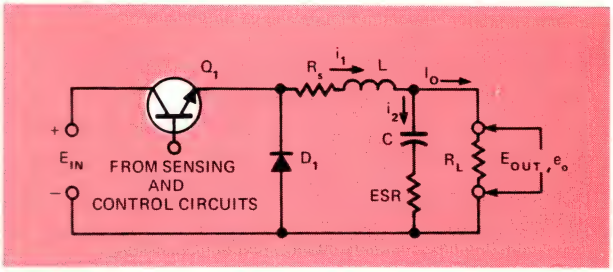
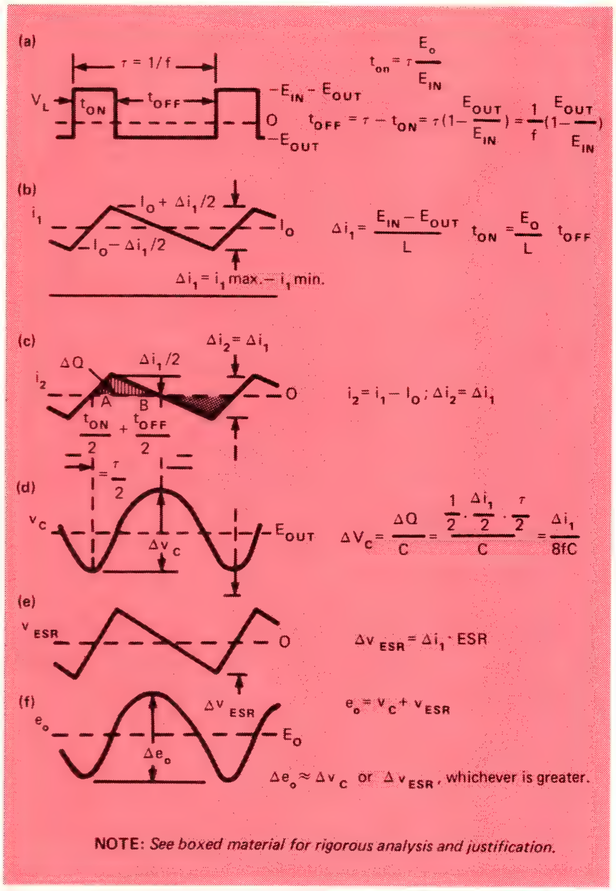


Fig. 1—The transistor switch (Q_1) in a switching regulator is either in the saturated state or completely nonconducting, according to input from the sensing and control circuits. Output voltage is regulated by changing the duty cycle of Q_1 which switches ON and OFF at a predetermined frequency.

These advantages result from the method of regulating the output voltage; namely, varying the duty cycle of a power-transistor switch. Because the switch (Q_1 in **Fig. 1**) is always in the saturated state when it is conducting, the power dissipated in the regulator is much lower than it would be in a series regulator for the same input and output conditions. Otherwise the switch is completely nonconducting, except for a brief commutation time between the ON and OFF states.


(a)
τ = 1/f
$t_{on} = \tau \frac{E_o}{E_{IN}}$
V_L
t_{ON}
t_{OFF}
$-E_{IN} - E_{OUT}$
O
$t_{OFF} = \tau - t_{ON} = \tau(1 - \frac{E_{OUT}}{E_{IN}}) = \frac{1}{f}(1 - \frac{E_{OUT}}{E_{IN}})$
$-E_{OUT}$
(b)
i_1
$I_O + \Delta i_1/2$
I_O
$I_O - \Delta i_1/2$
$\Delta i_1 = \frac{E_{IN} - E_{OUT}}{L} t_{ON} = \frac{E_O}{L} t_{OFF}$
$\Delta i_1 = i_1 \text{ max.} - i_1 \text{ min.}$
(c)
$\Delta i_2 = \Delta i_1$
ΔQ
$\Delta i_1/2$
i_2
O
A
B
$\frac{t_{ON}}{2} + \frac{t_{OFF}}{2}$
$= \frac{\tau}{2}$
$i_2 = i_1 - I_O ; \Delta i_2 = \Delta i_1$
(d)
v_C
E_{OUT}
Δv_C
$\Delta V_C = \frac{\Delta Q}{C} = \frac{\frac{1}{2} \cdot \frac{\Delta i_1}{2} \cdot \frac{\tau}{2}}{C} = \frac{\Delta i_1}{8fC}$
(e)
v_{ESR}
O
$\Delta v_{ESR} = \Delta i_1 \cdot ESR$
(f)
e_o
Δv_{ESR}
E_O
Δe_o
$e_o = v_C + v_{ESR}$
$\Delta e_o \approx \Delta v_C$ or Δv_{ESR}, whichever is greater.

NOTE: *See boxed material for rigorous analysis and justification.*

Fig. 2—Important switching-regulator waveforms and defining equations are shown here. The equations in this figure are simplified, which in the worst case will result in a higher operating frequency. However, component tolerances will cause larger deviations than the use of simplified equations.

How the switching regulator works

In our basic regulator, the control circuit causes Q_1 to switch ON and OFF at a predetermined frequency. During the time that Q_1 is ON (t_{ON}), the input voltage is applied to the input of the LC filter, causing current i_1 to increase. When Q_1 is OFF, the energy stored in the inductor (L) maintains current flow to the load, circulating through "catch" diode D_1. The input of the LC filter is now at 0V, i_1 decreases to its original value, and the cycle repeats.

The output voltage will equal the time average of the voltage at the input of the LC filter:

$$E_o = E_{in} \frac{t_{ON}}{\tau}$$

$$\text{where: } \tau = \frac{1}{f}$$

The control circuit senses and regulates E_o by controlling the duty cycle, $\alpha = t_{ON}/\tau$. If E_{in} increases, the control circuit will cause a corresponding reduction in the duty cycle (α) so as to maintain a constant E_o.

$$E_o = \alpha E_{in}$$

Fig. 2 shows some of the important waveforms and equations that define the operation of the switching regulator power circuit. We have made several simplifying assumptions here. The most significant ones are to neglect the saturation voltage of Q_1, the forward drop of D_1, and the series loss resistance (R_s) of the inductor L. The effect of these assumptions is discussed in the accompanying box.

The voltage across inductor L (**Fig. 2a**) equals ($E_{in} - E_o$) during t_{ON} and ($-E_o$) during t_{OFF}. Under equilibrium conditions, when output load current I_o is constant, the average voltage across L must, by definition, equal zero.

In **Fig. 2b** we see the current i_1 through the inductor. Under equilibrium output current conditions, the increase in current during t_{ON} (Δi_1) must equal the decrease in current during t_{OFF}. The average value of i_1 equals the output current I_o.

Current i_2 through the capacitor (**Fig. 2c**) is equal to ($i_1 - I_o$). The average value of $i_2 = 0$, and $\Delta i_2 = \Delta i_1$. Current i_2 causes a ripple voltage to appear at the output. The output ripple voltage (e_o) has two components, a capacitive component v_c, and a resistive component v_{ESR}, caused by the equivalent series resistance of the capacitor.

Fig. 2d shows the capacitive component (v_c) of the ripple voltage, which is the time integral of the capacitor current i_2. Note that v_c is the integral of a triangular wave and is not sinusoidal. Also note that v_c is in "quadrature" with i_2, in the sense that v_c min. and v_c max. occur at times A and B, midway in the t_{ON} and t_{OFF} intervals, when $i_2 = 0$. The total charge ΔQ, flowing into C, is computed

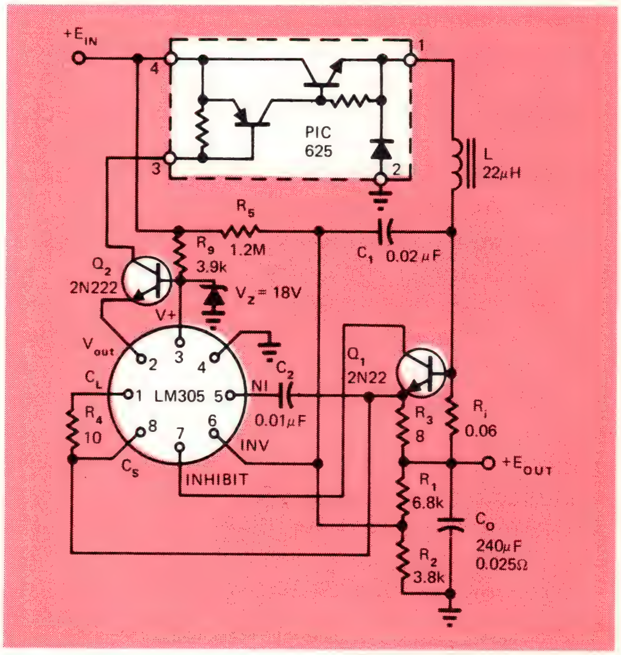


Fig. 3—This improved switching regulator, operating in the fixed-off-time mode, results in constant output ripple over wide ranges of input voltage and load current.

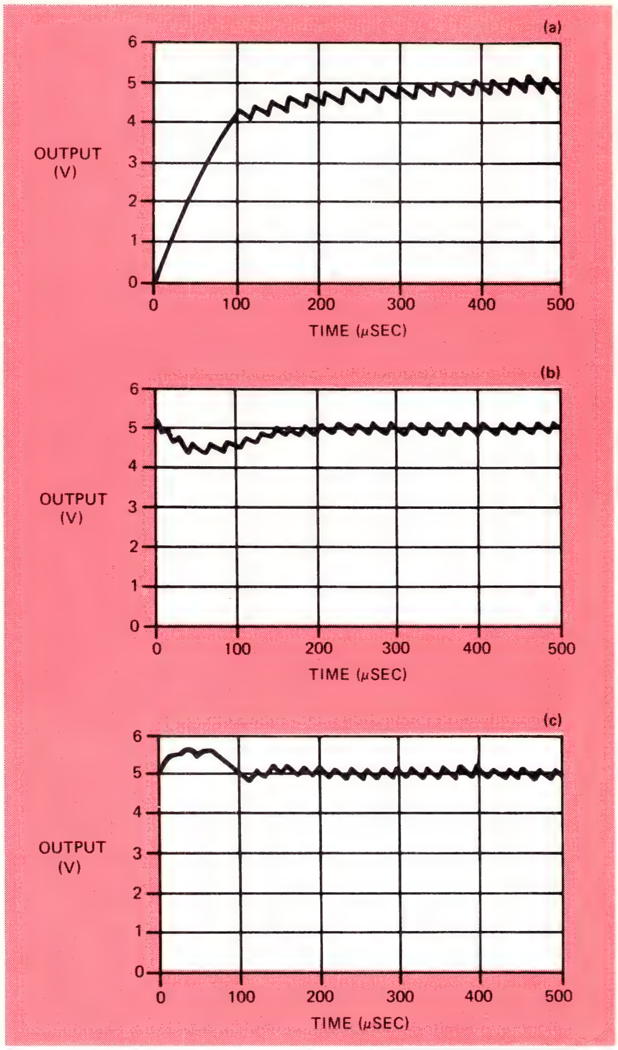


Fig. 4—Transient response of the switching regulator (**Fig. 3**) is shown for: (a) E_{in} from 0 to 25V. (b) I_o from 4A to 10A. (c) I_o from 10A to 4A.

graphically by finding the area of the triangular current waveform between time A and time B (Area = 1/2 bh; $\Delta Q = 1/2 \times \tau/2 \times \Delta i_2/2$). The peak-to-peak capacitive ripple component $\Delta v_c = \Delta Q/C = \Delta i_1/8\ fC$. (The factor 8f for a triangular current waveform is comparable to $2\pi f$ for a sinusoidal input current.)

The resistive component v_{ESR} of the ripple voltage (**Fig. 2e**) simply equals $i_2 \times$ ESR. It is in phase with i_2.

In Fig. 2f, the total output ripple voltage, e_o, is the sum of the waveforms in **Figs. 2d** and **e**. Note that since v_c and v_{ESR} are in quadrature, the greater of these two components dominates. For all practical purposes, the peak-to-peak output ripple voltage Δe_o is equal to either Δv_c or Δv_{ESR}, whichever is greater.

The magnitude of v_{ESR} in comparison with v_c shown in these waveforms is not exaggerated. Indeed, when designing a switching regulator to operate at frequencies greater than 20 kHz (to achieve small size and low cost in the L and C filter elements) the ESR of the capacitor usually dominates completely. Even when high-quality capacitors (low ESR) are employed, you usually have to use a larger capacitance value than would otherwise be required. This is in order to realize the ESR necessary to achieve the ripple objective of the design.

Overcoming Δf due to ESR

With conventional free-running switching regulator control circuits, capacitor ESR also causes very significant departure from the design frequency. This can result in large ripple magnitude, inductor saturation and switching transistor failure. In the following circuits, the frequency-variation effect caused by ESR is effectively eliminated, leaving only the ripple consideration. In addition, the following parametric relationships and circuit characteristics are easily and economically attained:

- The switching frequency can be selected and established at the optimum value for the switching components. This frequency will be independent of the value of the output capacitor's ESR.
- The value of t_{OFF} is held relatively constant over wide ranges of load current and input voltage, and is independent of the output capacitor's ESR. Constant t_{OFF} results in constant ripple current and output ripple voltage.
- Settable overcurrent limiting is provided, thereby protecting both the load and the switching transistors under all conditions. It prevents saturation of the power inductor during the startup transient period, minimizing startup overshoot.
- The overcurrent limiting circuit provides significantly lower power dissipation than conventional current-limit feedback arrangements.
- The drive current to the power output (switch) stage is regulated to a predetermined value for best efficiency and optimum switching speed. Drive current automatically increases at low temperatures and decreases at high temperatures, thereby maintaining optimum drive conditions for the power switch.

Note that although the use of this circuit approach permits essentially constant t_{OFF} operation, even with capacitors having relatively high ESR, the output ripple voltage is increased by high ESR. (If the ripple developed across the ESR is significantly larger than that developed across C, then the ripple is essentially proportional to ESR.)

Not all of the following circuits possess all of the virtues listed above, but the exceptions will be noted. **Fig. 3** typifies this family of regulators. Here, we've implemented it with the popular

LM305 regulator IC and a Unitrode Series PIC600 hybrid power switch. The latter consists of a quasi-Darlington switching transistor, a fast-recovery catch diode and switch bias resistors, all matched for optimum efficiency and switching speed (up to 100 kHz without derating). This configuration is a positive output regulator, with performance characteristics as follows:

E_{in} = 20 to 40V
E_o = 5V ± 1%
Δe_o = 100 mV p-p (2% p-p ripple)
I_o = 2 to 10A
I_{sc} = 12A

Regulation vs. E_{in} (20 to 40V)<25 mV
Transient recovery time for step change in load current from 2A to 10A, or 10A to 2A < 150 μsec.
f = 50 kHz nominal
Efficiency > 70%

Circuit operation

This circuit operates in the fixed-off-time mode; hence, output ripple is independent of input voltage over wide ranges. Two feedback signal paths are provided:

For dc feedback, a fraction of the dc output voltage is fed back to the inverting input of the LM305 through voltage divider R_1, R_2. The dc voltage at the inverting input is compared to a reference voltage (approximately 1.8V) within the LM305. The LM305 regulates E_o in such a way that the voltage returned to the inverting input is essentially equal to the built-in reference voltage. The R_1, R_2 divider ratio therefore establishes the level of the dc output voltage, E_O. Resistor R_5 improves output-voltage regulation vs. input-voltage changes by feeding a small compensating voltage, proportional to the input voltage, into the inverting input of the LM305.

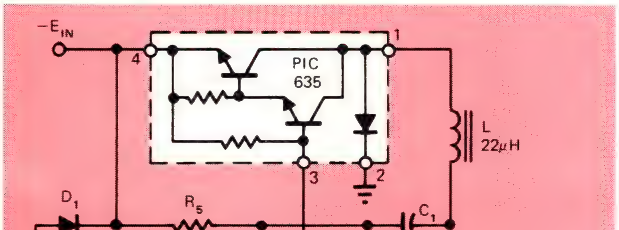


Fig. 5—Negative-output switching regulator is similar in operation to the circuit of **Fig. 3** except that current limiting is achieved by reducing the reference voltage to ground instead of turning off the base drive to the power-output switch.

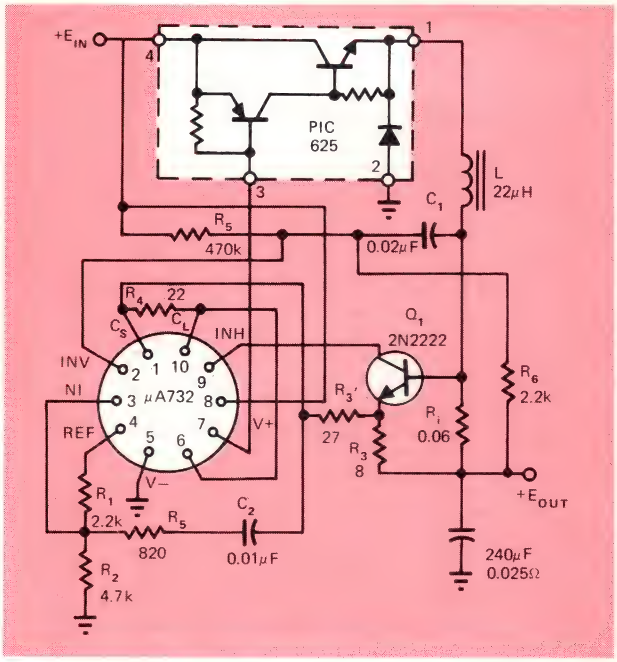


Fig. 6—A μA723 can also be used to achieve a positive-voltage switching regulator.

For ac feedback, capacitor C_1 returns an ac voltage waveform to the inverting input of the LM305. This voltage is proportional to the ac voltage, V_{R_I}, developed across R_I plus the output ripple voltage, Δe_o. Capacitor C_2 feeds back an ac voltage to the noninverting input of the LM305. This voltage is proportional to the ac voltage V_{R_3} across R_3 plus the output ripple voltage, Δe_o.

When the circuit values are properly established, the same fraction of Δe_o is fed back to both inverting and noninverting inputs, thereby effectively cancelling. The operation of the switching regulator is thus rendered independent of the output ripple voltage developed across the C or ESR of the output capacitor.

Since the Δe_o components cancel each other, the LM305 essentially compares Δv_{R_I} at the inverting input to Δv_{R_3} at the noninverting input. Voltage Δv_{R_3} is a rectangular waveform with p-p amplitude equal to $I_{drive} \times R_3$, where I_{drive} is the base drive to the hybrid switching transistor provided by the LM305. Δv_{R_I} is a triangular waveform with p-p amplitude equal to $\Delta i_1 \times R_I$, where Δ_1 is the ripple current through inductor L. When the drive current is on, Δv_{R_3} is at its peak positive amplitude. As i_1 increases, v_{R_I} increases proportionately. When the positive amplitude of Δv_{R_I} reaches Δv_{R_3}, this causes the LM305 to switch off the drive current. Then Δv_{R_3} immediately

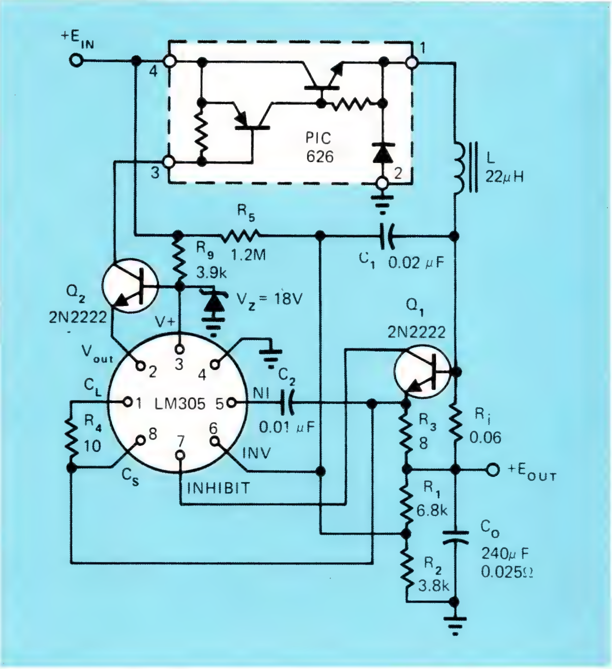


Fig. 7—High-voltage positive switching regulator uses an 18V zener in series with a 3.9k resistor to power the IC regulator. Transistor Q_2 provides base drive to the power switch and also isolates the LM305 output from the switch.

drops to it's peak negative amplitude and i_1 starts to fall. When Δv_{R_I} reaches a negative amplitude equal to Δv_{R_3}, the LM305 switches the drive current back on, and the process repeats. In this manner, the LM305 controls the power switch so that Δi_1 is fixed. Since $t_{OFF} = \Delta i_1 \times L/E_o$—with fixed values of L and E_o—t_{OFF} is fixed and independent of changes in E_{in} or capacitor C or ESR values.

R_4, connected between pins one and eight of the LM305, establishes the desired level of base drive for the PIC600 Series hybrid power switch. It determines the hysteresis voltage across R_3.

Current-limiting action is provided by transistor Q_1, whose collector is connected to the "gate" or "inhibit" terminal of the LM305 (pin seven). When the load current is normal, Q_1 is cut off and pin seven floats. But when the voltage drop across R_I increases to a value greater than the sum of V_{BE} (Q_1) and v_{R_3}, Q_1 turns ON. Thus it cuts off the drive current from the LM305 and, ultimately, the power switch. This cutoff action latches because v_{R_3} disappears with the drive cut off. This keeps Q_1 on until the current through R_I drops significantly—enough to make the voltage drop across R_I fall below the V_{BE} of Q_1.

The current through R_I, following such an overload cutoff action, falls linearly at the rate of E_o/L. When Q_1 is cut off, drive current is restored. The circuit will then continue to switch on and off at a frequency comparable to normal operation, with the average current limited at the design limit, and power dissipation held to safe values.

You will usually have to employ a noise filtering capacitor across the input of any switching regulator. This functions to prevent the steep waveform of the rectangular current pulse associated with the power switch turning on and off, from propagating into the E_{in} supply line. The capacitance value required is a function of the impedance characteristics of the E_{in} supply and the connecting wiring. Watch out for underdamped resonance with the inductance of the input wiring, or transient-induced ringing may occur. The input capacitor must have short leads, and the ground side should preferably be connected directly to the ground side of the output filter capacitor.

A 10A negative-voltage switching regulator utilizing an LM304 and PIC600 series is shown in **Fig. 5**. Resistors R_1 and R_2 determine the reference voltage. The error amplifier controls the output voltage at twice the voltage across R_2. Diode D_1 ensures a potential difference of 2V at the uregulated input (pin five) with respect to the reference supply (pin three). (If the unregulated supply terminal goes more than 2V positive with respect to the reference supply, the collector isolation junction of transistor Q_6 becomes forward-biased and disrupts the reference.)

Current limiting is achieved by reducing the reference voltage to ground with the help of Q_1 and R_8 (**Fig. 5**), instead of turning off the base drive to the power output switch as in **Fig. 3**. Aside from that, the functions of the rest of the components and the operation of the switching regulator are the same as described for **Fig. 3**.

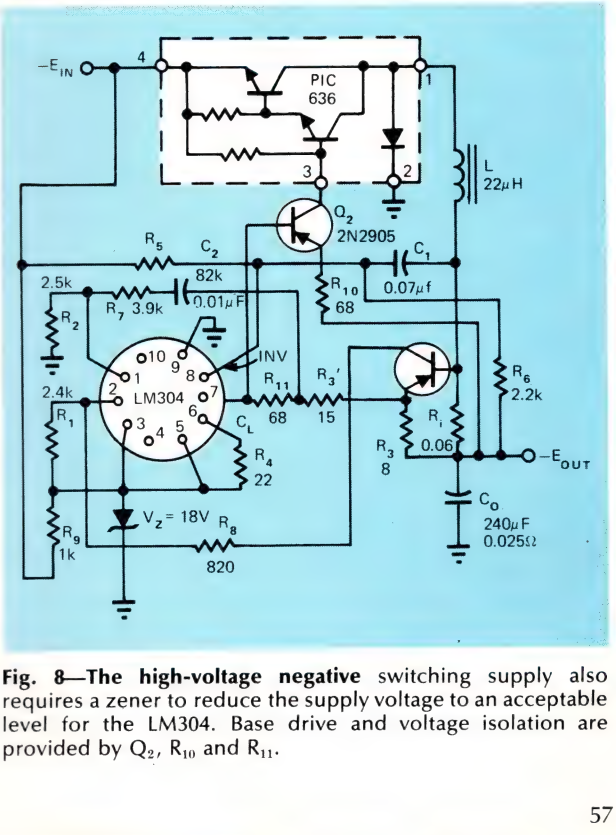


Fig. 8—The high-voltage negative switching supply also requires a zener to reduce the supply voltage to an acceptable level for the LM304. Base drive and voltage isolation are provided by Q_2, R_{10} and R_{11}.

Effects of simplified equations

The simplified equations used in this article neglect the effect of "catch" diode forward drop, V_F, transistor saturation voltage, V_{sat}, and the IR drops in the inductor and current sensing resistor, $I_o R_x$. If a design is implemented using the values of L, C, ESR, and Δi derived from the simplified equations, then t_{ON}, t_{OFF}, f and Δe_o will differ from the design values because of the effect of the simplifying assumptions (**Fig. 2b**):

Simplified:

$$\Delta i_1 = \frac{(E_{in} - E_o)\, t_{ON}}{L} \qquad \textbf{(1)}$$

Exact:

$$\Delta i_1 = \frac{(E_{in} - E_o - V_{sat} - I_o R_x) t_{ON}{}'}{L} \qquad \textbf{(2)}$$

Simplified:

$$\Delta i_1 = \frac{E_o\, t_{OFF}}{L} \qquad \textbf{(3)}$$

Exact:

$$\Delta i_1 = \frac{(E_o + V_D + I_o R_x)\, t_{OFF}{}'}{L} \qquad \textbf{(4)}$$

Note that Δi_1 is fixed because the circuit controls this value directly. Instead of the original design values of t_{ON} and t_{OFF}, actual values $t_{ON}{}'$ and $t_{OFF}{}'$ will be observed. Since Δi_1 is fixed, we can equate **Eqs. 1** to **2** and **3** to **4**:

$$\frac{t_{ON}{}'}{t_{ON}} = \frac{(E_{in} - E_o)}{(E_{in} - E_o - V_{sat} - I_o R_x)}$$

and

$$\frac{t_{OFF}{}'}{t_{OFF}} = \frac{E_o}{E_o + V_D + I_o R_x}$$

Although the actual $t_{OFF}{}'$ is less than the assumed t_{OFF}, $t_{ON}{}'$ is greater than the assumed t_{ON}. Thus their net effect on the operating frequency is reduced. In the worst case, when E_o is small (5V) and E_{in} is high (50V), the actual frequency will be 25% higher than the original assumed frequency. This will result in a very slight drop in efficiency. Output ripple component Δv_c will be smaller because of the higher frequency. Δv_{ESR} will not change because Δi_1 is fixed. Component tolerances usually result in larger deviations than those caused by the use of the simplified equations.

The only other assumption that could have possible significance is that the transistor switching times are negligible at the highest frequency of operation. The validity of the assumption is normally assured by selecting appropriate devices. This also applies to the speed of the control circuit. If delay time through the control circuit in addition to transistor turn-on and turn-off times is significant with respect to the total period τ, the consequent delay in turning the power circuit ON and OFF will cause a proportional increase in Δi_1 and Δe_o, and a proportional decrease in frequency.

Efficiency calculations

The efficiency of a switching regulator depends upon the factors given in the following equations:

$$\text{Efficiency} = \frac{P_{out}}{P_{in}} \times 100\%$$

$$= \frac{E_o \times I_o}{E_o \times I_o + P_T + P_D + p_T + p_D + P_L + P_I + p_c + P_c}$$

Note that each factor's worst case does not necessarily occur under the same conditions.

1. DC Losses—Transistor. (Worst case when E_{in} is lowest because t_{ON} is largest.)

   $$P_T = V_{CEsat} \times I_o \times \frac{t_{ON}}{\tau}$$

   where: $\frac{t_{ON}}{\tau} = \frac{E_o}{E_{in}}$

2. DC Losses—Diode. (Worst case when E_{in} is highest.)

   $$P_D = V_F \times I_o \times \frac{t_{OFF}}{\tau}$$

   where: $\frac{t_{OFF}}{\tau} = 1 - \frac{E_o}{E_{in}}$

3. Switching Losses—Transistor. (Worst case when E_{in} is high; $t_d + t_s$ do not contribute to power losses.)

   $$p_T = E_{in} \times I_o \frac{t_r + t_f}{2\tau}$$

   where: $t_r = t_{rv} + t_{ri}$
   $t_f = t_{fv} + t_{fi}$

4. Switching Losses—Diode. This is a very complex calculation unless diode recovery time is much smaller than the transistor rise time. This is because the diode will short-circuit the power supply prior to turn-off. Thus it affects the transistor dissipation, possibly causing second breakdown, and generates intolerable EMI. By using a diode whose recovery time is not more than half the transistor rise time, all these problems become negligible.

5. DC Losses—Inductor. (AC loses are negligible when Δi_1 is small compared to I_o.)

   $$P_L = I_o^2 \times R_s$$

   where: R_s is equal to effective series resistance of inductor.

6. DC Losses—Current Sense Resistor. (AC losses negligible when Δi_1 is small compared to I_o.)

   $$P_I = I_o^2 \times R_I$$

7. AC Losses—Capacitor. (Usually negligible.)

   $$p_c = \frac{\Delta i_1{}^2}{12} \times ESR$$

8. Control Circuit Losses. (Base drive to switching transistor is dominant, but usually negligible.)

   $$P_c = E_{in} \times I_o \times \frac{t_{ON}}{\tau} = E_o \times I_b$$

   where: $\frac{t_{ON}}{\tau} = \frac{E_o}{E_{in}}$

Fig. 6 shows a positive switching regulator using a μA723. The basic performance and circuit operation also is similar to **Fig. 3**.

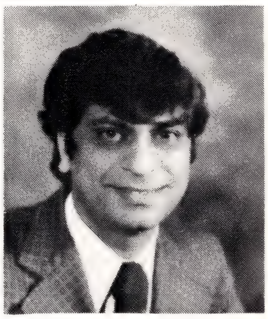
The circuit shown in **Fig. 7** is a high-voltage positive switching regulator. Because the LM305 (like most IC regulators) cannot be operated at supply voltage in excess of 40V, this circuit uses a fraction of E_{in} as a power supply for the IC circuit. This is done with a zener diode and the current limiting resistor R_9. Transistor Q_2 provides both the regulated base drive to the power switch and the necessary voltage isolation between LM305 and the switch.

The circuit of **Fig. 8** is similar to the low-voltage negative switching regulator with a minor modification. Transistor Q_2 and resistors R_{10} and R_{11} are all used to provide regulated base drive to the power output stage as well as to furnish the voltage isolation between power output stage and LM304. Resistor R_9 limits the current through the zener diode under steady-state and startup conditions. □

Part 2, discussing power-circuit design considerations, will appear in the Nov. 5, 1974 issue.

Author's biographies

Lloyd Dixon is director of applications engineering at Unitrode Corp., Watertown, MA. With them for 16 years, he previously co-founded Solid State Products, Inc., which merged with Unitrode in '67. Lloyd received his B.E.E. from RPI and is a member of IEEE, Tau Beta Pi and Eta Kappa Mu. He holds three patents and, in his leisure hours, enjoys sailing and cruising.



Raoji Patel, an applications engineer with Unitrode for the past three years, received both his BSEE and MSEE from the Univ. of Missouri. He is working presently in the field of power transistors and hybrid circuits and has been granted a patent for his "Emergency Lighting System." Married, with a 2-year old son, Raoji plays table tennis and chess.

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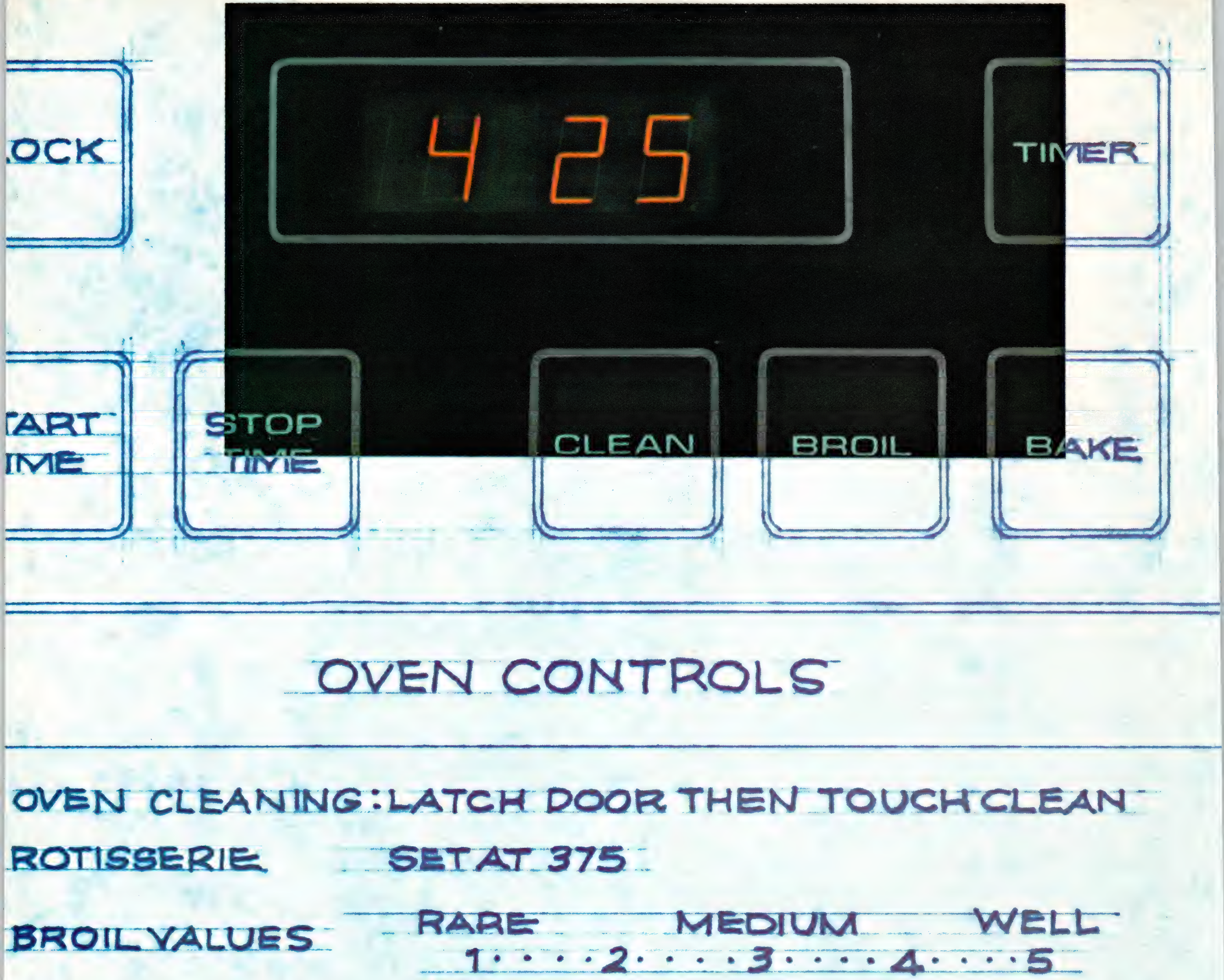

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October 1974

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aluminum	7	26	▼
tantalum	9	27	▼
Film	7	15	▼
Mica	4	18	▼
Paper	7	14	▼
Trimming	5	11	▼
CONNECTORS			
Coaxial	6	15	▲
Multipin circular			
high-density	13	21	▲
standard	5	11	=
Printed-circuit	4	10	▼
Rack & panel	4	12	=
INTEGRATED CIRCUITS			
DTL	6	15	▼
ECL	5	8	▼
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CMOS	4	19	▲
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PRINTED CIRCUITS			
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Two-sided	6	10	▼
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Crystal-can	10	15	=
Reed	7	10	▼
General-purpose	6	11	▲
Stepping	9	12	▼
Telephone	7	10	▼
Solid-state	7	10	=

	LEADTIME IN WEEKS MIN.	MAX.	TREND
RESISTORS, FIXED			
Composition	3	10	▼
Dep.-carbon & carbon-film	3	12	▼
Metal-film	5	19	▲
Wirewound	8	17	▲
RESISTORS, VARIABLE			
Nonwirewound			
nonprecision	4	11	=
precision	3	10	▼
Trimmers	3	11	▼
Wirewound			
nonprecision	4	12	▲
precision	4	12	▼
trimmers	4	12	▲
SEMICONDUCTORS			
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Power rectifiers	5	11	=
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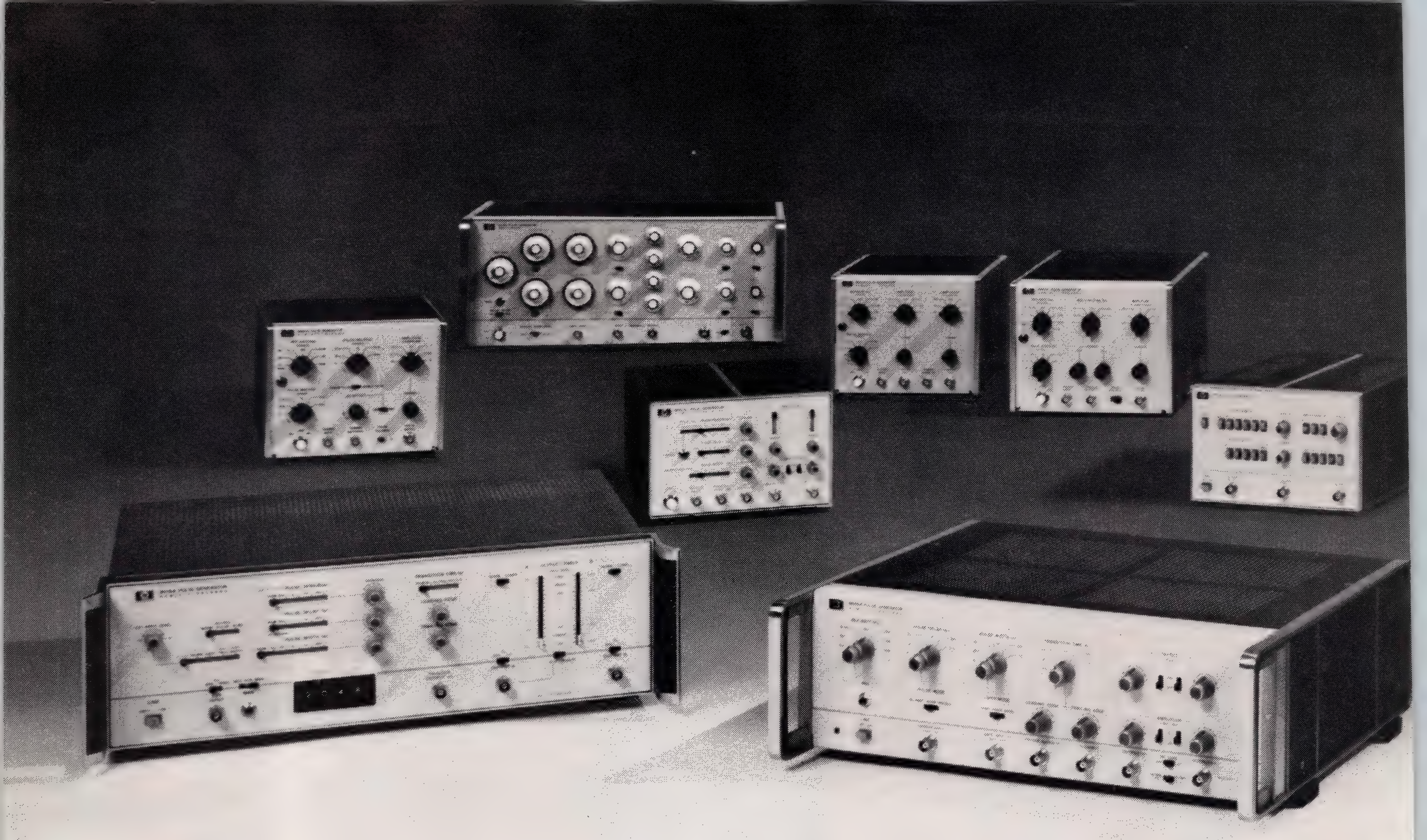

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CMOS counter circuitry slashes battery power requirements

Every milliampere of battery drain counts in portable instruments, so the savings made possible by CMOS warrant a close look.

Don Aldridge, Motorola

Designed with low-powered logic, this 5-MHz counter makes small demands on its batteries, yet provides good performance. To further conserve power, its LED display blanks out when there is no input signal to the counter.

Both performance-optimized and power-minimized counter versions are described, along with input signal conditioning and display multiplexing. In either design, the power required by the digital logic is in the order of mW, with most

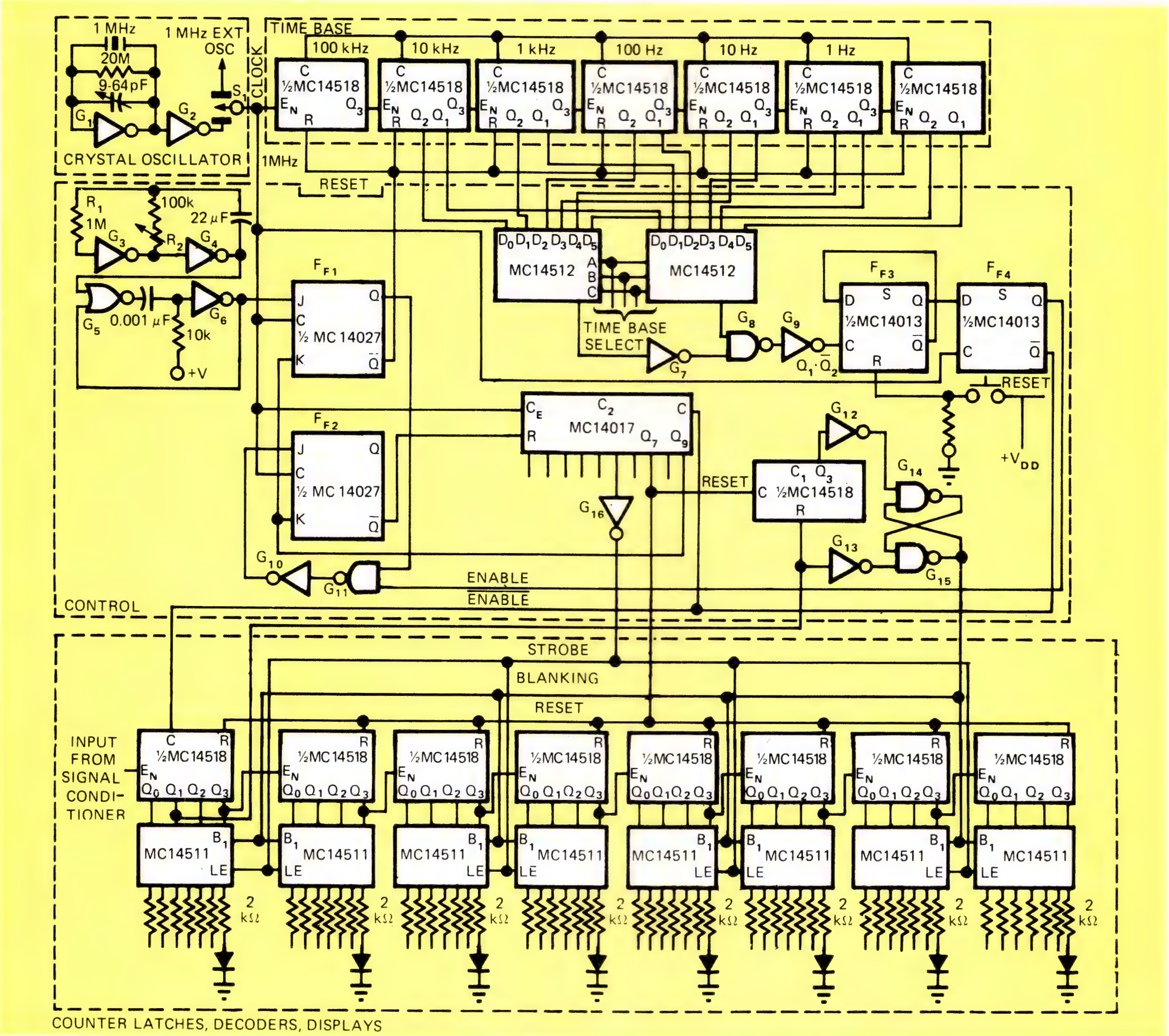


Fig. 1—Basic 5-MHz counter for 12V operation, showing all functional sections except the front end.

of the total drain attributable to the digital readout.

Performance-optimized (5-MHz) version

Ignoring input signal conditioning for the moment, **Fig. 1** shows the counter's basic configuration. It is designed for 12V operation, and for use with a 10-MHz linear front end (designed for maximum frequency response and sensitivity). Four major sections will be discussed separately: the crystal oscillator and time base; the counter, latches, decoders and displays; the control functions and the front end.

Crystal oscillator and time base. Time-base circuitry determines the duration of the enable time. Its reference frequency is obtained from a 1-MHz crystal oscillator which uses a CMOS gate, G_1, with a crystal for the feedback element. Gate G_2 serves as a buffer for the 1-MHz oscillator. Provisions have been made for using an external reference frequency, which must have a 0-10V swing to drive the time-base counters. This may be used when a more stable reference oscillator is desired.

The time base divides the 1-MHz oscillator frequency down to the desired enable time by using MC14518 dual decade counters. Three and a half dual counters, connected in a ripple-through mode, are used to provide a maximum enable period of 10 sec. Counter operation of this sort has the advantage of simplicity, but the disadvantage of a time delay from the input of the first counter to the output of the last one. The control section of the counter provides compensation for this time delay. The compensation is discussed in the control section.

Counters, latches, decoders and displays. As in time-base circuits, the actual counting of the input signal employs MC14518 dual BCD counters. Although the CMOS logic family is capable of operation over a wide voltage range, the highest frequency operation is obtained at the higher supply voltages. For that reason, an operating voltage of 12V was chosen. At 10V the CMOS MC14518's have a minimum toggle frequency of 2.5 MHz (typical value is 6 MHz). Also 12V is a convenient value for portable operation. The series of eight BCD counters (four dual counters) employs the ripple mode of operation.

The latches and BCD-to-7-segment decoders are constructed with MC14511's. These CMOS parts contain latches with a strobe control and the decoder for a 7-segment display, along with a blanking-control pin for turning the displays off. Power drain can be conserved by using the blanking to turn the displays off when there is no input signal. One half of dual BCD counter C_1 and the flip-flop made from 2-input NAND gates G_{12} through G_{15} performs this turnoff. If four counter (control) reset pulses are received on the BCD counter with no input signal, the displays are blanked out, conserving power. If there is an input signal, C_1 is constantly reset by Q_1 of the first MC14518 counter, keeping the displays in the ON state.

Multiplexing of the displays, which will be discussed later, results in a slightly lower cost and lower power dissipation. However, it increases package count and circuit complexity.

This section (counters, latches, decoders and displays) has three control inputs. The first is the enable line, which turns the first counter on and off for the precise enable time period. The second, the strobe line, transfers the count into the memory of the MC14511 latch decoder. The control line resets the MC14518 decade counters to ready them for the next count cycle.

Monsanto MAN-4 LED displays were chosen for this counter because of their wide acceptance and their compatibility with the MC14511 7-segment decoder driver.

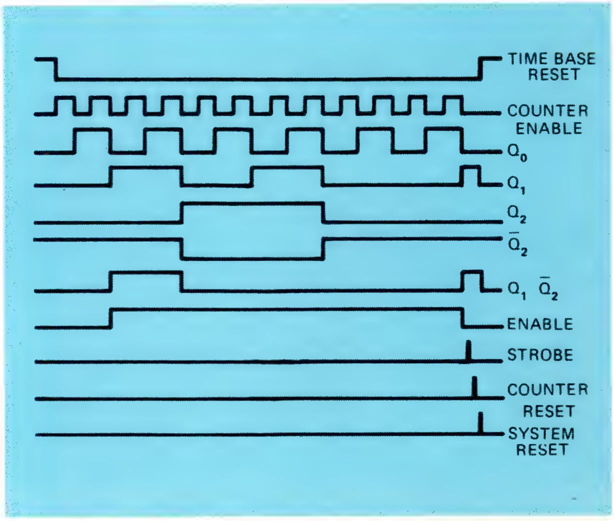


Fig. 2—Timing diagram for the basic counter of Fig. 1.

Control. The control section processes the precise timing signals from the time base to provide the enable period, strobe pulse and reset pulse to the "counter, latch, decoder" section. A 5-μsec pulse from the low-frequency oscillator and one-shot in the control section starts the counting cycle. Gates G_3 and G_4 make up the low-frequency oscillator and gates G_5 and G_6 make up the one-shot. The 5-μsec pulse occurs at intervals from 0.1 to 10 sec, depending upon the setting of pot R_2.

If the counting cycle was run at the minimum enable time, the count would be updated into the latches at this cycle time. In the case of a 10-μsec time base, the count would be updated at a

100-kHz rate. Any instability in the input waveform would cause the last few digits of the display to change at the 100-kHz rate—which would result in an unreadable flickering of the display. Therefore, the count cycle is operated at a much slower rate, in this case the previously-mentioned 0.1- to 10-sec rate.

Once through lightly. The sequence starts with a 5-µsec pulse from the low-frequency oscillator and one-shot. This pulse toggles $\overline{Q}$ of FF_1 low, removing the reset from the time-base counters and permitting them to divide down the 1-MHz clock. **Fig. 2** shows a timing diagram of the resulting sequence. The enable input of the selected timebase counter and three of its outputs, Q_0 through Q_2, are shown. By "ANDing" Q_1 and Q_2 together, two pulses with starting edges equal to the desired time base are formed. The gate delays through the time base are equal for both pulses, thus compensating for the delays. These pulses are applied to the input of FF_3 which is one half of a MC14013 D flip-flop.

In FF_3, wired as a toggle flip-flop, the first pulse sets the Q output HIGH and the second pulse resets it LOW. The three NAND gates G_7, G_8, G_9 decode the $Q_1 \times \overline{Q}_2$ signal from the desired timebase counter. The MC14512 selects this counter—or a 2-pole, 6-position switch may be used. These 8-channel data selectors choose one of eight channels of information via 3-bit binary control lines.

Flip-flop FF_4 insures that the edges of the enable pulse occur exactly coincident with the 1-MHz clock pulses. The delays through the time base and data selector are constant for both turn-on and turn-off pulses. Hence they cancel and the waveform appearing at the $\overline{Q}$ output of FF_4 is a precisely controlled time period. This time period is the enable or gating time.

Operations that remain to be performed during the counting sequence are the strobe pulse, counter-reset pulse and control-system reset pulse. These are derived with the MC14017 Johnson counter C_2, flip-flop FF_2 and associated gates. Until the end of the enable pulse, the Johnson counter is disabled through either the clock line or the reset line. At the end of the enable pulse, the Johnson counter is enabled and begins to count the 1-MHz clock frequency. Of the 10 outputs of the counter, Q_5 goes high for 1 µsec after the sixth clock pulse. This is used as the strobe pulse. After the eighth clock pulse, Q_7 goes high and the counters are reset. The tenth clock pulse resets the control system, via FF_1 and FF_2. Now the control system awaits another pulse from either the low-frequency oscillator and one-shot or an external pulse generator (which could synchronize the counting cycle with some external event).

10-MHz linear front end. The input signal for the basic frequency counter must swing from a logic ZERO (0V) to a logic ONE (about 10V). Therefore a functional block is needed to translate from any input waveform shape and waveform level to a signal capable of toggling the CMOS counters. Also the input to this block should have a high impedance to prevent disturbing the input wave form when making the frequency measurement. This block will contain a high-impedance buffer, with or without amplification, connected with a Schmitt trigger for waveform shaping. Also the input should be protected from very large signals.

For this version the front-end design shown in **Fig. 3** was chosen. It consists of a FET and bipolar buffer, followed by a Schmitt trigger made from an MC75108 dual line receiver. This front end will operate up to 10 MHz with a 25-mV input signal.

The MC75108 line receiver operates from a ±6V power supply but can be biased up to operate from a single +12V supply. In addition to both positive and negative power supplies, the line receiver requires a ground connection at the midpoint of the supply voltages. The data sheet of the MC75108 indicates a typical positive supply current of 18 mA and a negative supply current of −8.4 mA. Thus the ground pin returns about 10 mA to the positive supply. For single-supply operation, the positive supply pin is connected to the +12V supply while the negative one is connected to the counter ground. The ground pin on the line receiver must then be returned to

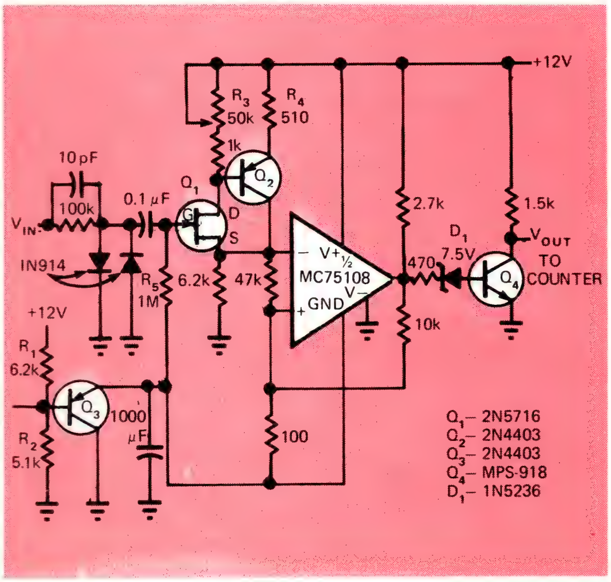


Fig. 3—Performance optimized, this 10-MHz linear front end provides best frequency response and sensitivity.

a 6V reference capable of sinking up to a maximum of 15 mA. PNP transistor Q_3 and resistors R_1 and R_2 serve as a simple voltage regulator for the 6V reference.

N-channel JFET, Q_1, and pnp bipolar, Q_2, comprise a unity-gain high-impedance buffer for the line receiver. Potentiometer R_3 adjusts the buffer output voltage to equal that of the 6V reference for maximum sensitivity.

Under normal operation with a split supply, the output of the MC75108 swings from zero to the positive supply voltage. Since the line receiver is biased up by 6V, the output swing is now from 6 to 12V. This swing must be translated to voltage levels compatible with CMOS operating at +12V. Translation is done with the 7.5V zener, D_1, and transistor Q_4. When the output of the line receiver is at 6V, both the zener and Q_4 are OFF. When the output of the line receiver is in the HIGH state, D_1 conducts and Q_4 turns ON. The output voltage swings from cutoff to saturation of Q_4 (about 0.5 to 12V).

MC75108 is a dual line receiver. Its power consumption is constant whether or not both line receivers are used. The two receivers can provide two separate input channels with a switch to select between them, or they can be so connected to the basic counter that they switch on and off alternating with each count cycle. Thus the first count cycle would look at channel "A," the second count cycle at channel "B."

Power-minimized (1-MHz) version

Although the counter already described was quite reasonable in its power demands, it was optimized for maximum performance.

For many applications, power-dissipation considerations are of top importance, and decreasing power consumption to the lowest practical amount may more than justify some sacrifice of frequency response and sensitivity.

COUNTER TYPE	"MAXIMUM PERFORMANCE"	"MINIMUM POWER"
MAX. FREQ.	5 MHz	1 MHz
SENSITIVITY AT MAX. FREQ.	10 mV	120 mV
BASIC COUNTER DRAIN	10 mA	2 mA
FRONT-END DRAIN (NO INPUT SIG.)	25 mA	6 μA
FRONT-END DRAIN (1MHz SIG.)	25 mA	180 μA
DISPLAY DRAIN	225 mA	70 mA
SUPPLY VOLTAGE	+12V	+6V
TOTAL CURRENT	260 mA	72 mA
TOTAL POWER	3.12W	0.43W

Table 1—Performance data on the two counter versions.

Any power-consumption optimization of the frequency counter should first involve an analysis of where the major portions of the power are consumed. **Table 1** shows performance comparisons between the high-performance counter previously discussed and the low-power counter that follows.

Because the largest portion of the counter's power consumption is by its digital displays, the obvious way to reduce consumption would be to choose the lowest power display type and then optimize for it. Such an approach will not be pursued further in this article. However, we will discuss ways to conserve power when using a LED display.

Multiplexing saves power. In the basic performance-optimized counter previously discussed, the MAN-4 displays were operated at 4 mA/segment. While this drive produces a bright and easily read display, it takes a great deal of power.

Fig. 4 shows a technique which operates the displays at a lower power level by multiplexing a single decoder driver between all of them. Multiplexing of a digital display is a technique of time-sharing the circuit components. It allows the eye to integrate the readout over the total time period which makes the display appear continuous. Multiplexing reduces the overall cost of the counter while increasing the complexity of design. With it the displays are operated at a peak current of 20 mA, but at a duty cycle of only 12.5%, which results in reduced power consumption. Also, the counter is operated from a 6V supply, which reduces total consumption.

Four MC14021 8-bit shift registers implement the multiplexing. These shift registers have both parallel and serial inputs, and not only permit a unique way of multiplexing, but also provide latches needed to store the count from the MC14518 counter chain. BCD outputs of the MC14518 counter chain are connected to the parallel inputs of the shift register. The least significant BCD bit of each of the eight counters is connected to each of the eight inputs of the first shift register. The next most significant bits of the eight counters are connected to the eight inputs of the next shift register. Thus, the eight 4-bit BCD words require four 8-bit shift registers. The eighth output of each shift register is connected to the series input of the same register, making the digital word in the shift register shift around in a loop from the first bit through to the last bit.

When a logic ONE is applied to the parallel/

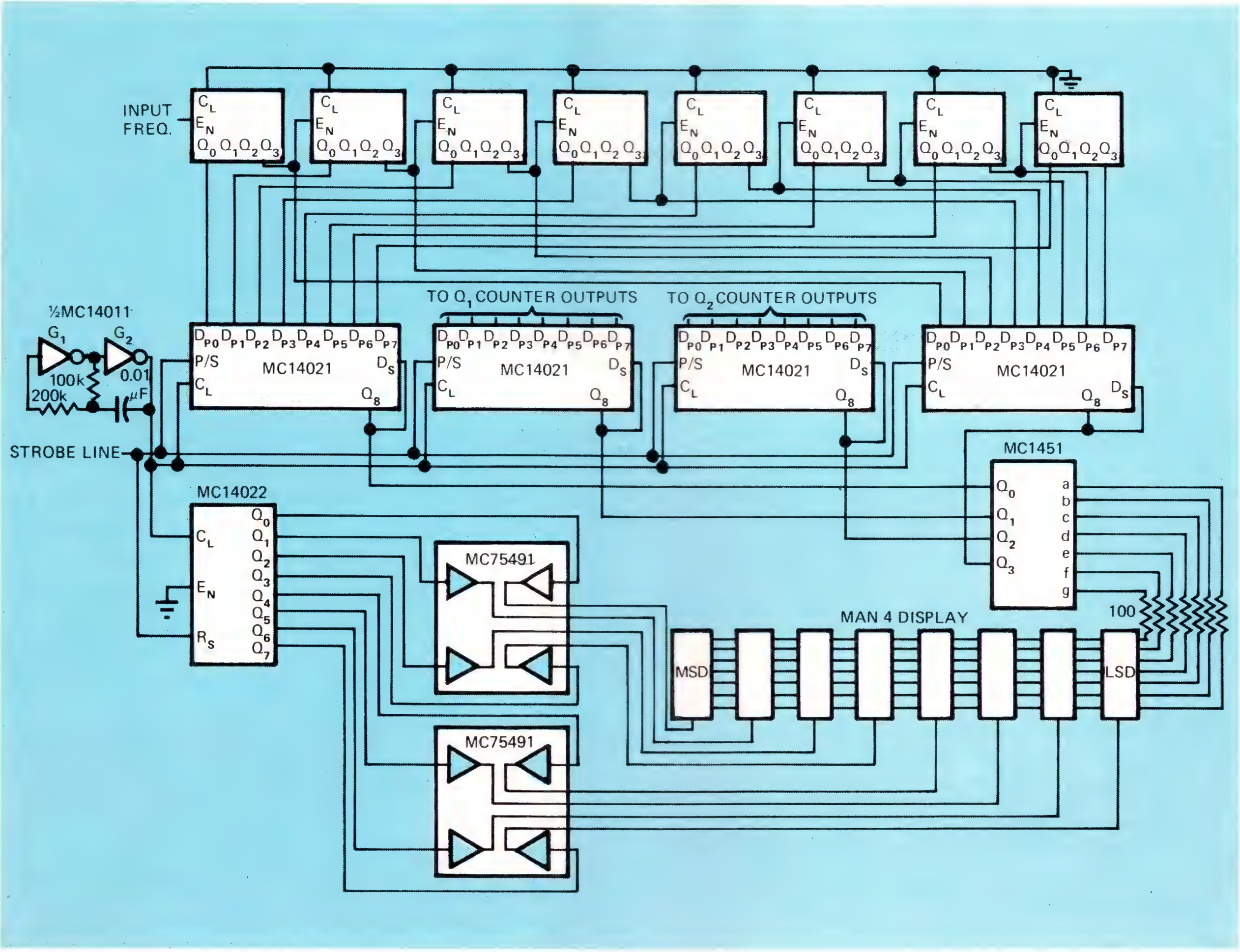


Fig. 4—Multiplexing with a single decoder driver adds complexity but saves power.

series control line of the shift registers, digital information on the parallel inputs is loaded into the register. The control signal is the strobe pulse from the counter control section. Then, after the register returns to series operation, the digital word is shifted around through the registers, with each of the eight bits of information appearing at the inputs to the single 7-segment decoder. An MC14022 octal counter/divider keeps track of which counter digit is being applied to the 7-segment decoder input. An oscillator constructed from gates G_1 and G_2 provides the clock signal for both digit selection and the shift register. This oscillator controls the multiplex frequency, and the values shown result in a frequency of about 1 kHz. The outputs of the MC14022 digit selector are buffered through the MC75491 LED drivers and fed to the MAN-4 display cathodes. The anodes of the MAN-4's are driven directly from the MC14511 BCD-to-7-segment decoder.

This multiplexing results in an overall reduction in both power consumption and system cost. However, it increases system complexity and somewhat decreases the display brightness.

Low-power 2-MHz front end. Another area with possibilities for reducing power dissipation is the signal conditioning or front end section. The front end previously described was optimized for maximum performance from the CMOS counters, as opposed to optimizing for absolute minimum power dissipation. The "performance" design not only draws about 25 mA from the 12V supply, but this current is constant whether an

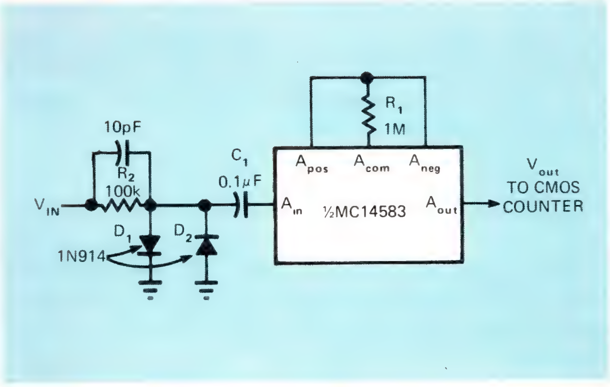


Fig. 5—Power-miser 2-MHz CMOS front end draws current proportional to the input frequency.

input signal is present or not.

Fig. 5 details a low-power front end circuit for the counter. This design both reduces the power consumption and makes it proportional to the input frequency. With no input signal to the front end, current drain is only a few μA. Half of a MC14583 CMOS Schmitt trigger forms the power-economy front end. It operates from the single 6V power supply used in the low-power counter. A single resistor, R_1, sets the threshold voltages from both the HIGH and LOW logic states. Also the same overvoltage protection network used with the high-performance front end is employed in front of the MC14583 Schmitt trigger.

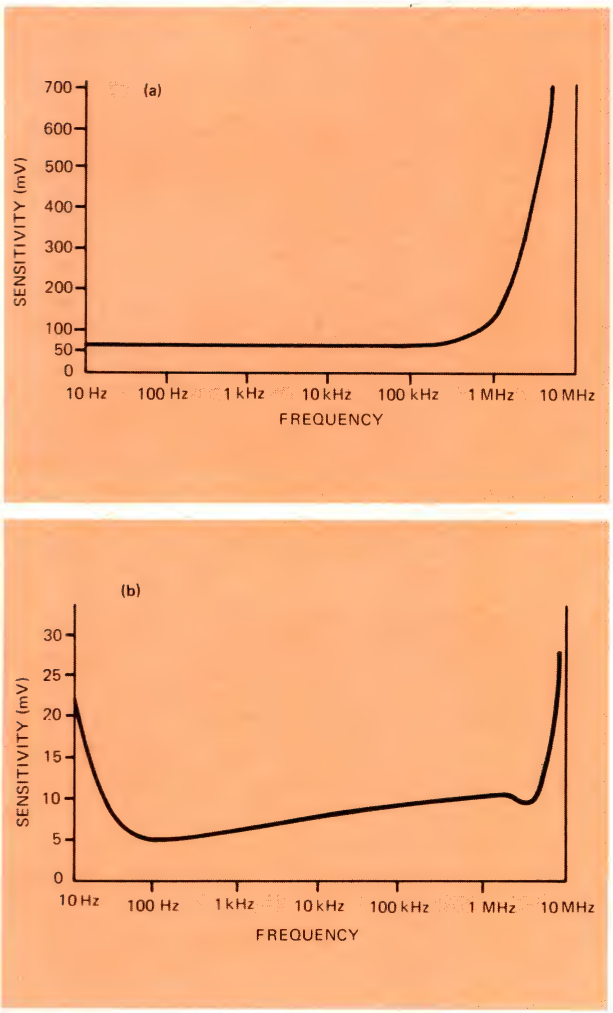


Fig. 6—Counter input sensitivity with the CMOS front end (**a**), and the high-performance one (**b**).

Reduced power consumption has its price—a sacrifice in overall performance. It decreases both the input sensitivity and the upper frequency limit. When using the CMOS front end, the upper frequency limit is about 3 MHz and input sensitivity is 400 mV. However, the front end's overall power consumption is considerably reduced. **Fig. 6** shows sensitivity vs. input-frequency curves for both the low-power and high-performance versions of the counter. **Table 1** compares details of their power consumption.

Battery choice. Using the **Table 1** information, a battery can be selected that will provide the desired compromise between operating life and battery size. It may be a throwaway nonrechargeable unit or one of the many types of rechargeables. In the case of rechargeable batteries, the method of charging depends on the type of battery. It may be as simple as a transformer, rectifier and current-limiting resistor or a very complex unit with discharge indicators, timing circuitry or automatic recharge circuitry. The manufacturer of the selected battery should be consulted as to the proper method of charging. Also, Motorola application note AN447 offers information dealing with Ni-Cad battery charging.

For the lab prototype counters we've described, the Globe Battery Co.'s GC1245 and GC626 batteries were chosen for the 12 and 6V models, respectively. The 12V one has a rating of 4.5 Ahr, that will provide about 17 hours of continuous operation with the high-performance counter. Similarly, the 6V unit's 2.6 Ahr capacity will allow approximately 32 hours of continuous operation from the power-minimized model. Weight of the 6V battery is only about a third that of the 12V one, thus allowing a reduction of the overall package weight and bulk.

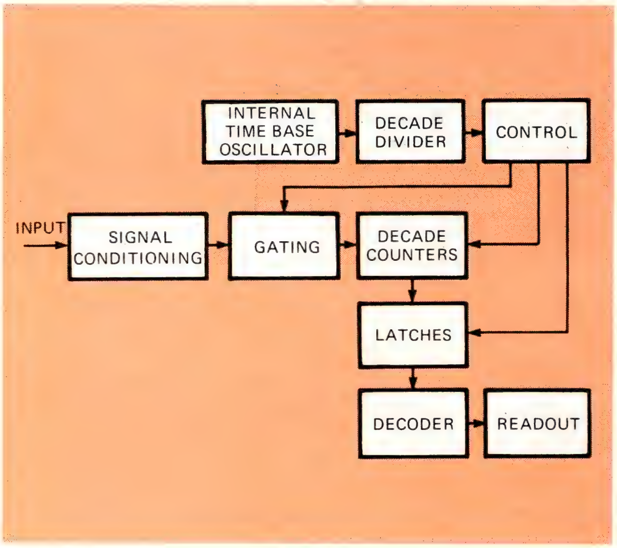


Fig. 7—The basic elements of an electronic frequency counter.

What can we conclude?

First that using CMOS permits very low-power operation in frequency counters. Second, that attention to the display power can be very rewarding, for when CMOS logic has been used, the lion's share of total power is consumed by the display. □

What is a frequency counter?

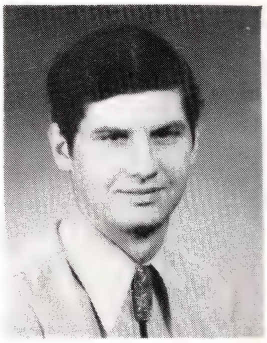
A frequency counter's basic function is to count the number of events/unit time. In the case of electronic frequency counters, these events are transitions between two voltage levels. The actual counting operation takes place during a precise time period called the "gate" or "enable period." A crystal oscillator plus a series of decade dividers usually generates this time period. The number of decade dividers selected determines the enable time.

Transitions of the input voltage from one logic state to the other are counted by a series of decade counters. The number of times the counters have been toggled during the enable time, then, equals the frequency of the input signal.

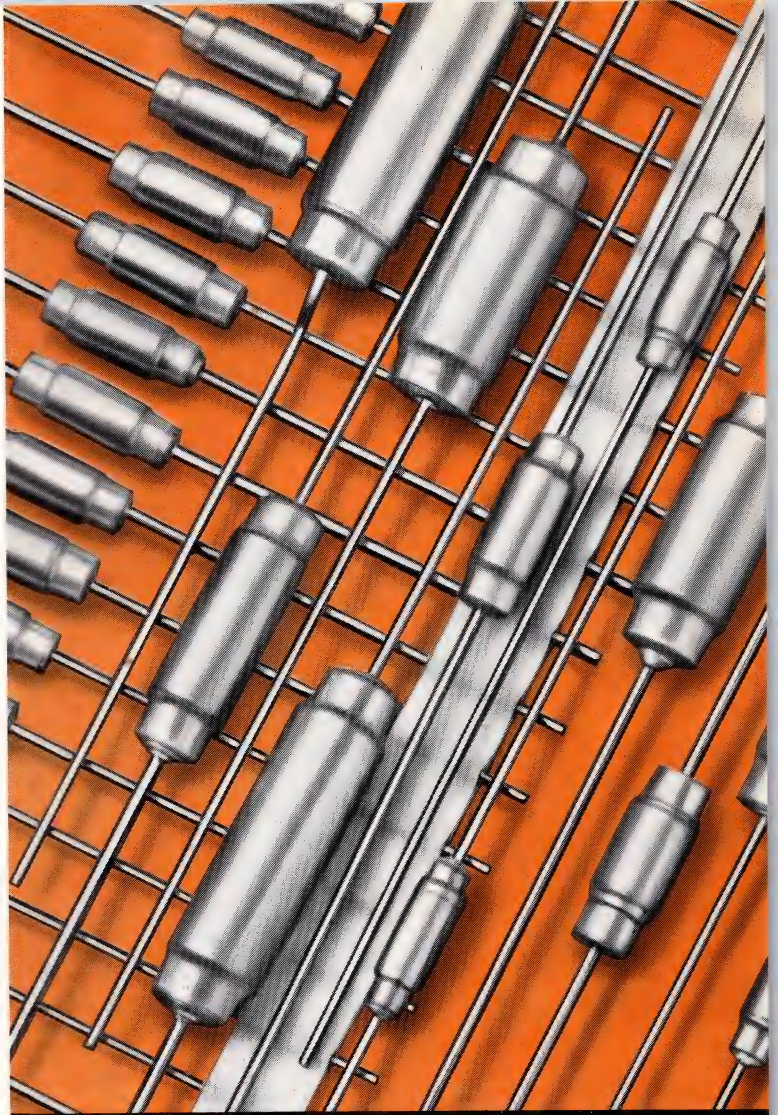
The counting sequence consists of three steps: enable or gating time, strobing the count into latches and resetting of counters. **Fig. 7** shows a block diagram of a basic frequency counter.

Operating sequence is started with the enable pulse, which allows the counters to count. At the end of the enable pulse, the counter output is strobed or transferred into the latches and displayed on the digital readouts. Afterward, the counters are reset and the cycle repeats. While the counters are reset and the sequence repeated, the latches hold the count information.

Author's biography



Don Aldridge is an industrial applications engineer employed by the Semiconductor Products Div. of Motorola, Inc. in Phoenix, AZ. His present work involves A/D, D/A, op-amp and other applications. Don holds a BSEE from Univ. of Missouri. His two spare-time hobbies, photography and ham radio, help keep him busy.



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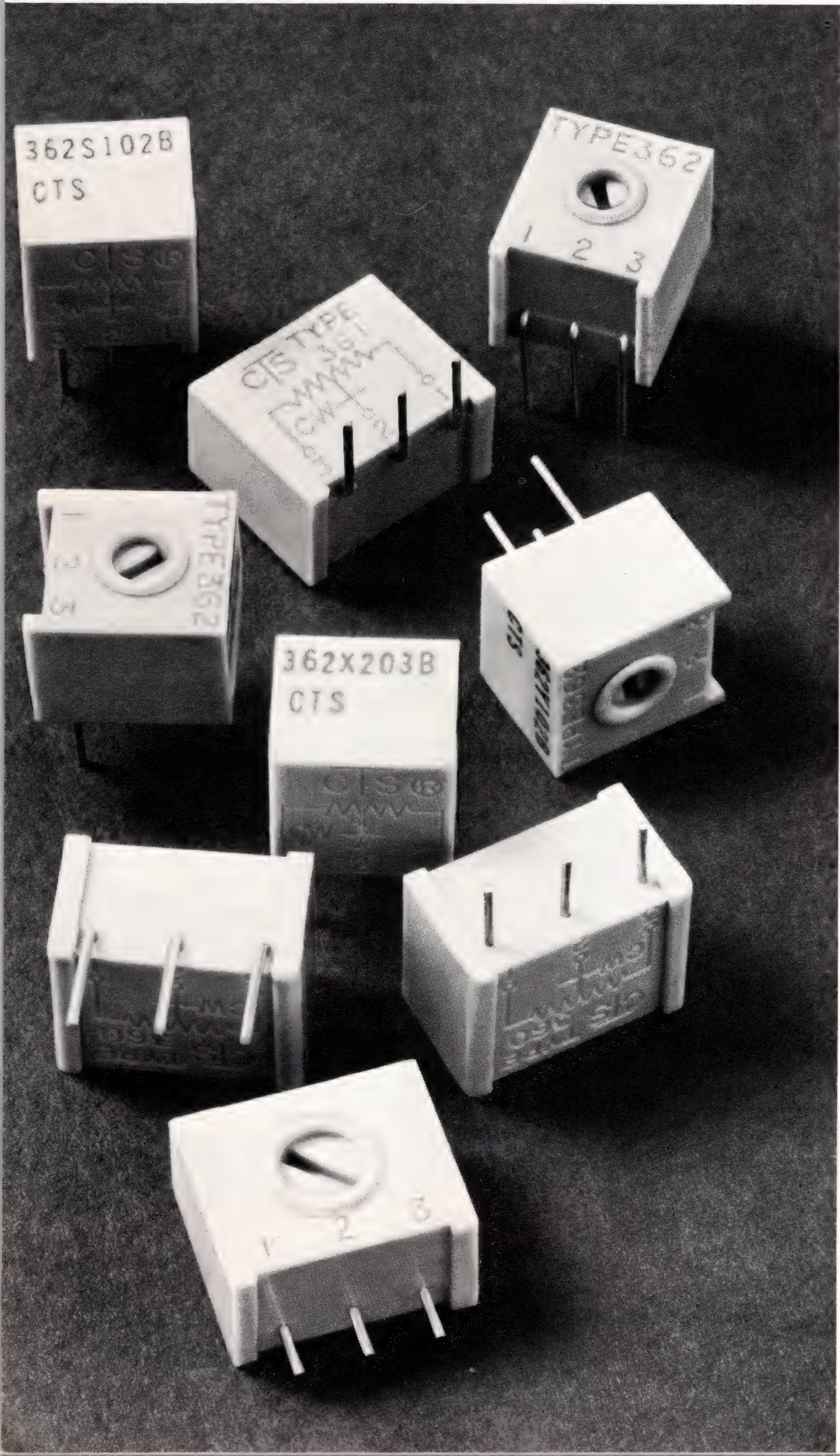

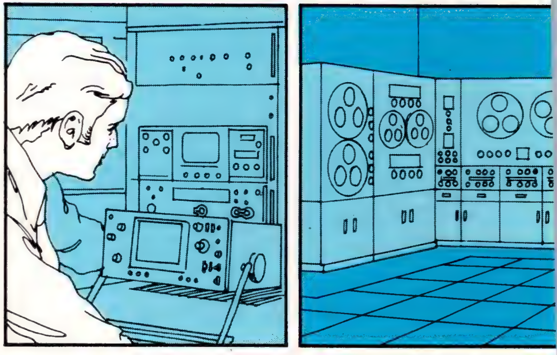

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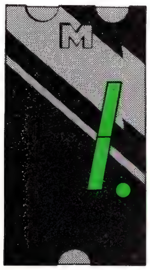


MAN 51
Common Anode;
Right Hand
Decimal

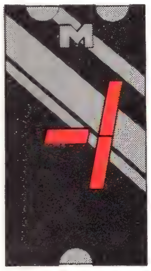
MAN 52
Common Anode;
Left Hand
Decimal

MAN 53
Common Anode;
Overflow (±1)

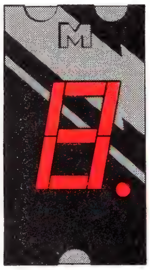
MAN 54
Common Cathode;
Right Hand
Decimal

MAN 71
Common Anode;
Right Hand
Decimal

MAN 72
Common Anode;
Left Hand
Decimal



MAN 73
Common Anode;
Overflow (±1)



MAN 74
Common Cathode;
Right Hand
Decimal

MAN 81
Common Anode;
Right Hand
Decimal

MAN 82
Common Anode;
Left Hand
Decimal

MAN 83
Common Anode;
Overflow (±1)

MAN 84
Common Cathode;
Right Hand
Decimal

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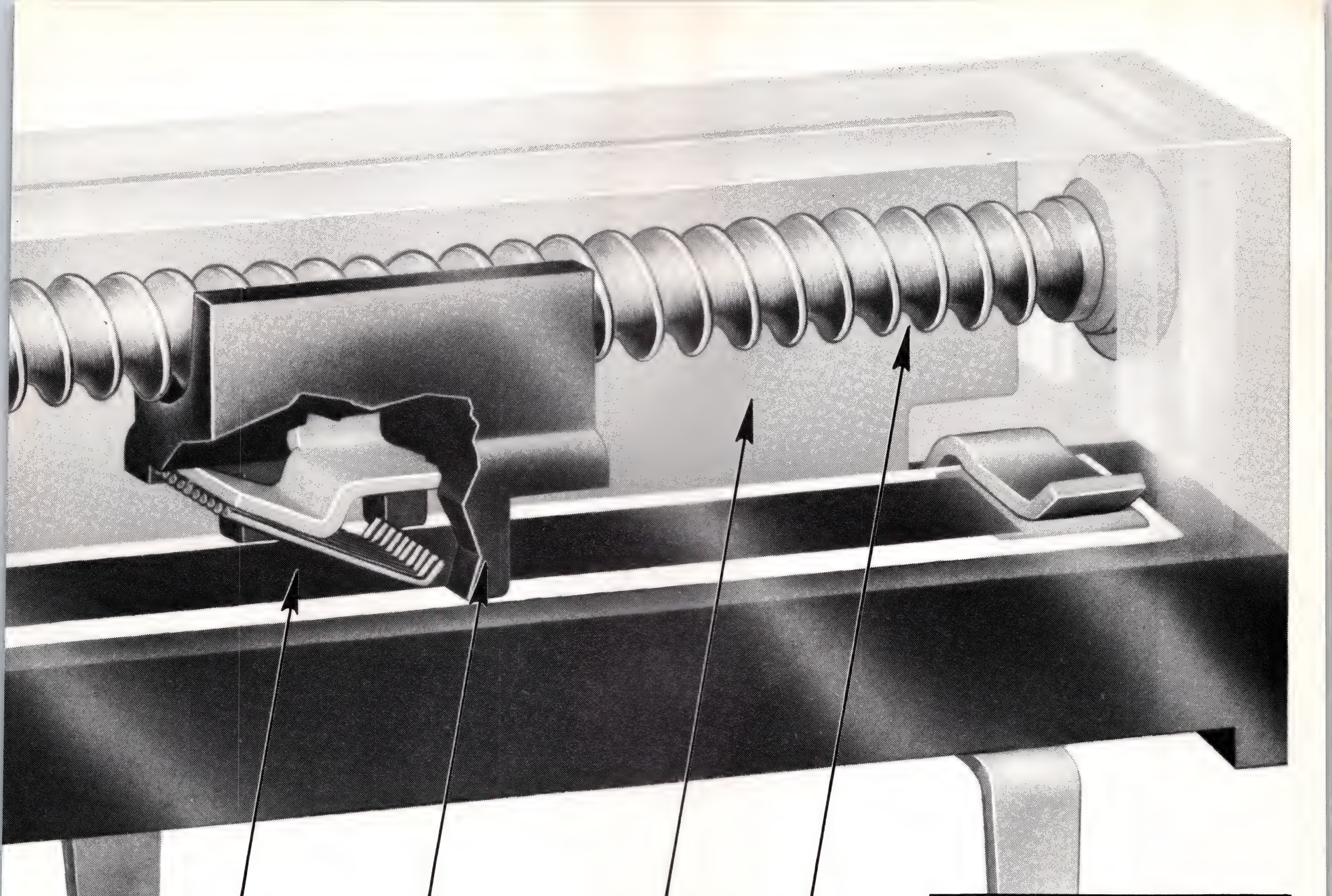

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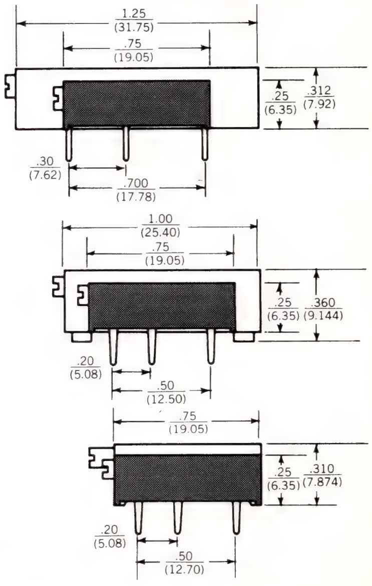

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Designers' Guide to: Active Filters, Part 3

Don't forget the lowpass prototype developed in Part 2. It's vital to the transformation techniques discussed in this installment.

Marvin Patterson, Hewlett Packard Co.

In Part 2, we discussed the derivations required to implement lowpass filters. You could go through the derivations again for the highpass or bandpass cases if you wanted to. However, you can achieve the same end by taking the results obtained for the lowpass filter, and simply transforming them to fulfill your requirement.

It is, in fact, a standard filter design approach to initially find the lowpass prototype. We found the prototype when we developed **Eq. 38** in Part 2. This approach is taken because it is much simpler to use the lowpass case to optimize everything. Having the lowpass prototype in hand, it is easy to transform variables and to realize any highpass, bandpass or lowpass transfer function desired. An example will best serve to illustrate the transformation techniques.

Lowpass to highpass the easy way

The lowpass prototype, **Eq. 38**, can be transformed

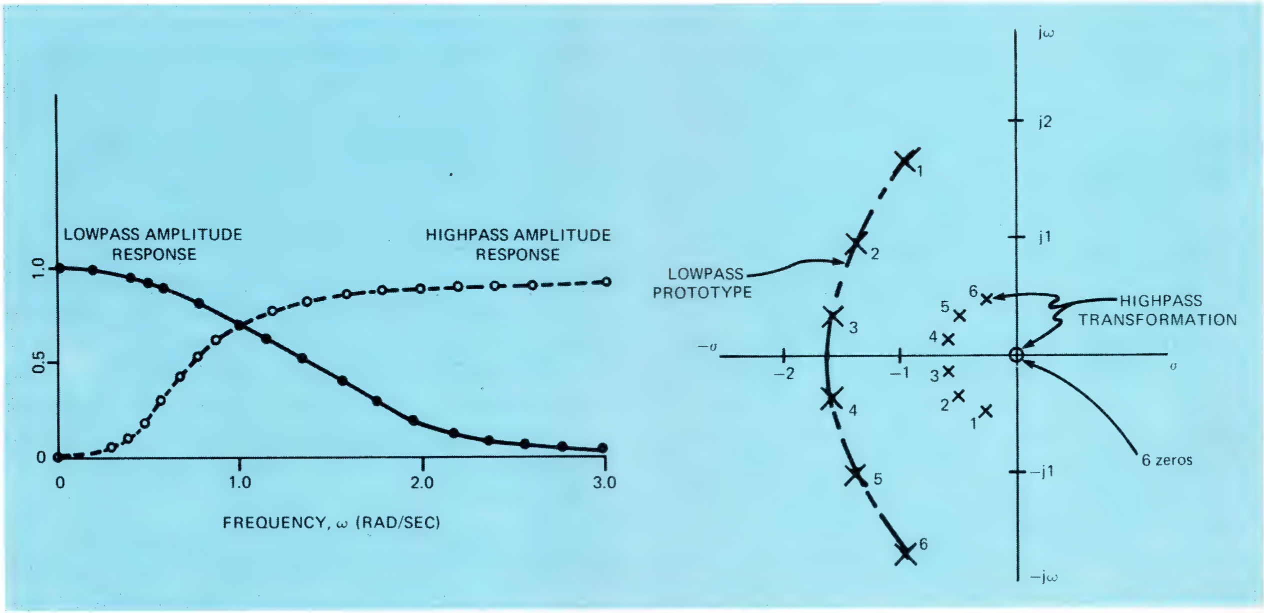

Fig. 12—Poles of highpass transformation will be the inverse of those of the lowpass prototype.

to a highpass prototype by letting:

$$p = \frac{1}{p'} \tag{42}$$

where p′ is the normalized complex frequency variable for the highpass prototype. Substituting this relationship into **Eq. 38**, and multiplying the resulting numerator and denominator by $(p')^n$ gives:

$$A(p') = \frac{p_0 p_1 \overset{*}{p}_1 \;\ldots\; p_m \overset{*}{p}_m \,(p')^n}{(1 + p_0 p')(1 + p_1 p')(1 + \overset{*}{p}_1\, p')\ldots(1 + \overset{*}{p}_m\, p')} \tag{43}$$

Returning the denominator to standard form, and cancelling common factors, yields the final form of the highpass prototype.

$$A(p') = \frac{(p')^n}{\left(p' + \frac{1}{p_0}\right)\left(p' + \frac{1}{p_1}\right)\left(p' + \frac{1}{\overset{*}{p}_1}\right)\ldots\left(p' + \frac{1}{\overset{*}{p}_m}\right)} \tag{44}$$

Under steady-state sinusoidal conditions, $p = jx$, $p' = jx'$, and $x' = 1/x$. Inspection of **Eq. 44** verifies that a highpass function has resulted from the transformation. As p′ starts positive from $+j0$ (corresponding to $p = -j\infty$), $A(jx')$ is equal to zero. As p′ approaches $+j\infty$ (corresponding to p approaching zero from the $-j\omega$ direction), $A(jx')$ approaches unity. Furthermore, setting $p' = j1$ in **Eq. 44** is equivalent to setting $p = -j1$ in **Eq. 38**. The result, in both cases, is a 3-dB cutoff point with a positive amplitude slope.

Further inspection of **Eq. 44** shows that each pole of the lowpass prototype has been transformed into its inverse. A specific highpass prototype can thus be constructed from its corresponding lowpass prototype by changing the numerator to $(p')^n$, and writing the denominator so that poles occur at the inverse of the lowpass poles. Substituting s/ω_c for p′ in the highpass prototype will then give the transfer function of a highpass filter having the desired type of response and the specified cutoff frequency, ω_c. An example of this transformation is illustrated in **Fig. 12**.

Implementation of the final circuit parallels that of the lowpass case covered in Part 2. Active 2-pole highpass stages **(Fig. 13)** are used in cascade to provide the complex poles. A passive highpass R-C section will provide any required real pole.

An interesting special case of the highpass transformation occurs with the Butterworth pole configuration. The normalized Butterworth lowpass prototype has poles equally spaced around a semicircle of unit radius in the left half of the p plane. These poles map, through the inverse relationship, into their own complex conjugates. Since complex poles only occur in complex conjugate pairs, the final highpass pole geometry is identical to the lowpass geometry. The only difference between the pole-zero plots of the lowpass and highpass Butterworth transfer functions is that the highpass plot has a zero at the origin for each pole whereas the lowpass plot has no zeros.

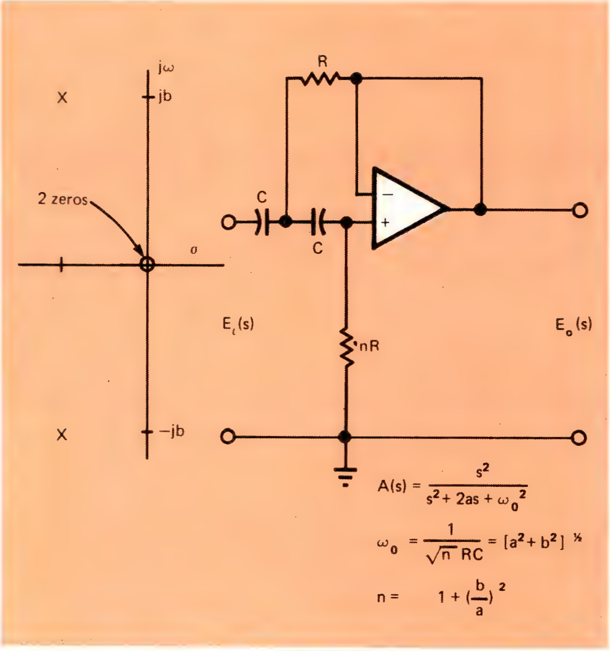
jω
jb
X
2 zeros
σ
X
−jb
R
C
C
−
+
$E_i(s)$
$E_o(s)$
nR
$A(s) = \frac{s^2}{s^2 + 2as + \omega_0^2}$
$\omega_0 = \frac{1}{\sqrt{n}\,RC} = [a^2 + b^2]^{½}$
$n = 1 + (\frac{b}{a})^2$

Fig. 13—Two-pole highpass circuits can be cascaded to implement **Eq. 44**.

Allpass transformation no problem

While allpass filters have no variation in amplitude response with respect to frequency, they do introduce a frequency dependent phase shift. An example of a useful allpass filter is a delay line. The maximally flat time-delay characteristic of the Bessel phase response is sometimes useful in allpass filters since it yields a time delay that is relatively independent of frequency.

The effect of a pole on amplitude response is inversely proportional to the length of the vector drawn in the p plane from the pole to the point jx on the vertical axis **(Ref. 8)**. Conversely, a zero affects amplitude in a manner that is directly proportional to the length of the vector drawn from the zero to the point jx. The lowpass amplitude response is thus determined only by vectors drawn from poles in the left-half plane. If zeros are placed in the right-half plane in a geometry that is the exact mirror-image of the pole geometry, the amplitude response due to the zeros will be the exact inverse of the lowpass amplitude response. The combined network, with poles in the left-half plane offset by zeros in the right-half plane, will thus have a constant amplitude response with respect to frequency.

Inspection will show, however, that each zero contributes a phase shift equal to the one contributed by the mirror-imaged pole. Thus, the phase response of the overall network is exactly double that of the corresponding lowpass filter.

The allpass prototype can be expressed as:

$$A(p) = \frac{(p - p_0)(p - p_1)(p - \overset{*}{p_1}) \ \ldots \ (p - p_m)(p - \overset{*}{p_m})}{(p + p_0)(p + p_1)(p + \overset{*}{p_1}) \ \ldots \ (p + p_m)(p + \overset{*}{p_m})} \qquad \textbf{(45)}$$

This can be factored into two basic types of subfunctions.

$$F_1(p) = \frac{p - p_0}{p + p_0} \qquad \textbf{(46)}$$

$$F_2(p) = \frac{(p - p_i)(p - \overset{*}{p_i})}{(p + p_i)(p + \overset{*}{p_i})} \qquad \textbf{(47)}$$

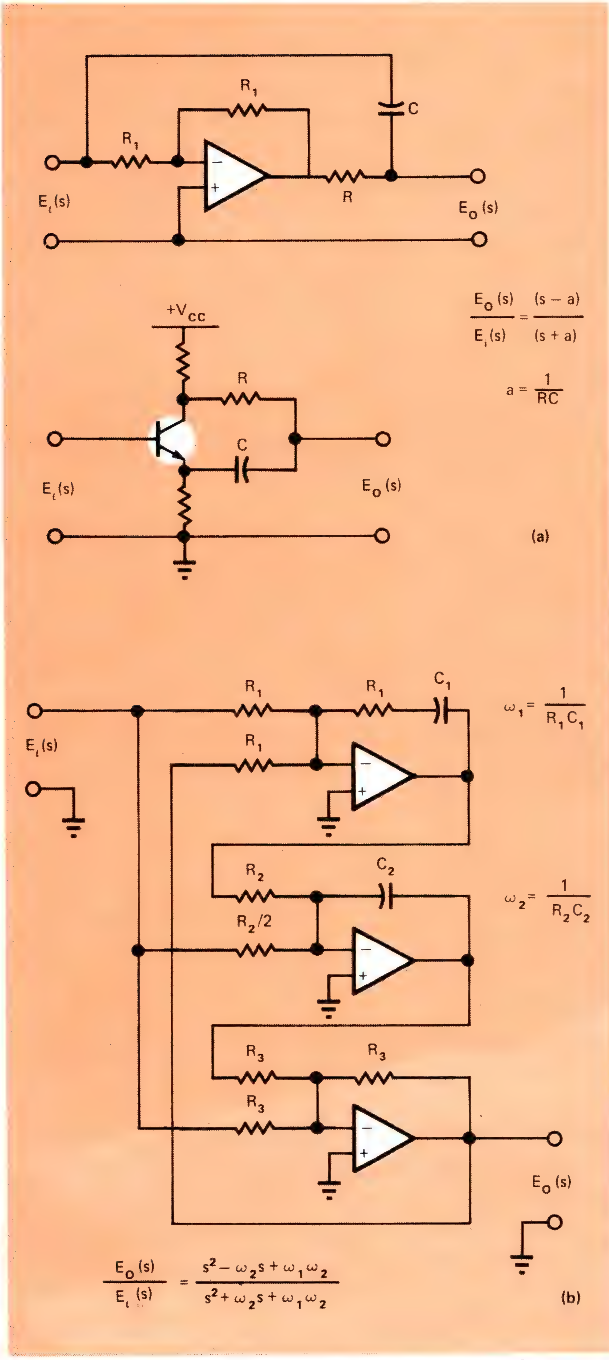
R$_1$
C
R$_1$
R
E$_i$(s)
E$_o$(s)
+V$_{CC}$
R
C
E$_i$(s)
E$_o$(s)
$\frac{E_o(s)}{E_i(s)} = \frac{(s - a)}{(s + a)}$
$a = \frac{1}{RC}$
(a)
R$_1$
R$_1$
C$_1$
$\omega_1 = \frac{1}{R_1C_1}$
E$_i$(s)
R$_1$
R$_2$
C$_2$
$\omega_2 = \frac{1}{R_2C_2}$
R$_2$/2
R$_3$
R$_3$
R$_3$
E$_o$(s)
$\frac{E_o(s)}{E_i(s)} = \frac{s^2 - \omega_2 s + \omega_1\omega_2}{s^2 + \omega_2 s + \omega_1\omega_2}$
(b)

Fig. 14—Cascading the single-pole (a) and 2-pole (b) allpass circuits provides twice the phase shift of the corresponding lowpass prototype.

Circuit implementations for these functions are illustrated in **Fig. 14**. These circuits can be cascaded to provide an allpass response that exhibits exactly two times the phase shift of the corresponding lowpass prototype. Although this network has no amplitude cutoff, the phase response can be scaled with respect to frequency by substituting s/ω_c for p and then multiplying both the numerator and denominator by ω_c.

You can transform to bandpass too

Given the lowpass prototype transfer function of **Eq. 38**, consider the transformation **(Ref. 9):**

$$p = q\left(\frac{s}{\omega_0} + \frac{\omega_0}{s}\right) \qquad \textbf{(48)}$$

$$\text{where } q = \frac{\omega_0}{\omega_B} \qquad \textbf{(49)}$$

The complex frequency variable for the bandpass response is s; ω_0 and ω_B are, respectively, the center frequency and bandwidth of the desired bandpass response. For sinusoidal steady-state, $p = jx$, $s = j\omega$ and **Eq. 48** reduces to:

$$x = q\left(\frac{\omega}{\omega_0} - \frac{\omega_0}{\omega}\right) \qquad \textbf{(50)}$$

Inspecting this expression shows that, when x is zero, ω is equal to $\pm\,\omega_0$; when x is $+\infty$, ω is either approaching $+\infty$ or zero from the negative side. When x is $-\infty$, ω is either approaching $-\infty$ or zero from the positive side. Substituting **Eq. 48** into **Eq. 38** should then transform the lowpass response into a pair of bandpass functions centered around $\pm\,\omega_0$.

Amplitude 3-dB cutoff occurs in a lowpass prototype when $x = \pm 1$. Solving **Eq. 50** for ω when $x = \pm 1$ yields:

$$\omega_c^+ = \frac{\omega_B}{2} \pm \omega_0\left[1 + \frac{1}{4q^2}\right]^{1/2} \qquad \textbf{(51)}$$

Similiarly, when $x = -1$:

$$\omega_c^- = -\frac{\omega_B}{2} \pm \omega_0\left[1 + \frac{1}{4q^2}\right]^{1/2} \qquad \textbf{(52)}$$

The positive signs in the above expressions are used for the positive frequency side of the bandpass response. The frequencies ω_c^+ and ω_c^- correspond to the upper and lower 3-dB cutoff points, respectively. These frequencies are related to the center frequency and bandwidth by:

$$\omega_0 = (\omega_c^+ \ \omega_c^-)^{1/2} \qquad \textbf{(53)}$$

$$\omega_B = \omega_c^+ - \omega_c^- \qquad \textbf{(54)}$$

when ω_0, ω_c^+, and ω_c^- are all positive.

The transformed bandpass of the lowpass prototype transfer function is found by substituting **Eq. 48** into

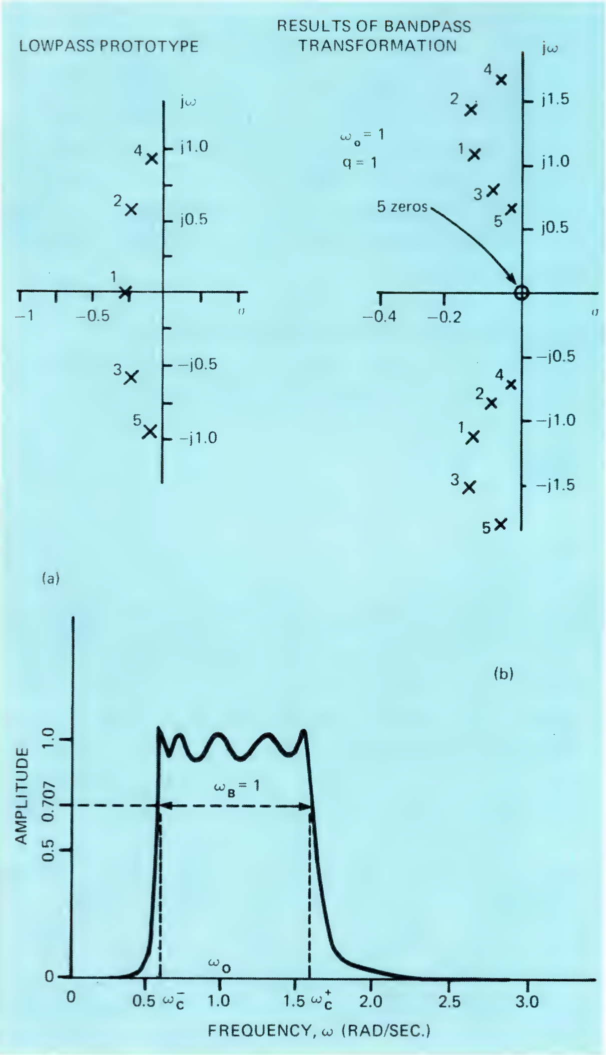

Fig. 15—Each lowpass pole gives two bandpass poles and a zero.

Eq. 38. This gives:

$$A(s) = \frac{p_0 p_1 p_1^* \ \ldots \ p_m p_m^*}{\left[q\left(\frac{s}{\omega_0}+\frac{\omega_0}{s}\right)+p_0\right] \ldots \left[q\left(\frac{s}{\omega_0}+\frac{\omega_0}{s}\right)+p_m^*\right]} \qquad \textbf{(55)}$$

Multiplying the numerator and denominator by $\left(\frac{\omega_0}{q}s\right)^n$ produces:

$$A(s) = \frac{p_0 p_1 p_1^* \ \ldots \ p_m p_m^* \left(\frac{\omega_0}{q}s\right)^n}{\left(s^2 + p_0\frac{\omega_0}{q}s + \omega_0^2\right) \ldots \left(s^2 + p_m^*\frac{\omega_0}{q}s + \omega_0^2\right)} \qquad \textbf{(56)}$$

Inspection will show that at $s = j\omega_0$, this expression equals one, and at either $s = j0$ or $s = j\infty$ it equals zero.

Comparing **Eq. 56** with **Eq. 38** reveals that each linear factor in the lowpass denominator transforms into an s term in the bandpass numerator and a quadratic term in the denominator. Each lowpass pole thus transforms into a zero at the origin, and a pair of poles not necessarily complex conjugates.

Consider first the single real pole at $p = -p_0$ that might occur in the lowpass prototype. It transforms into a pair of poles, located at the solutions of:

$$s^2 + p_0\frac{\omega_0}{q}s + \omega_0^2 = 0 \qquad \textbf{(57)}$$

or at:

$$S_{1,2} = -\frac{p_0\omega_0}{2q} \pm j\omega_0\left(1 - \frac{p_0^2}{4q^2}\right)^{1/2} \qquad \textbf{(58)}$$

Through a similar but more involved process, each complex lowpass pole can be shown to transform into a zero at the origin and a pair of nonconjugate poles. When the lowpass poles are considered in conjugate pairs, however, the bandpass equivalent consists of two zeros at the origin and two pairs of complex conjugate poles. For a lowpass pole pair located at $p = -a \pm jb$, the corresponding bandpass poles occur at:

$$S_{1,2} = \frac{\omega_0}{2q}\left[\left(-a + M\ \mathrm{Sin}\ \frac{\theta}{2}\right) \pm j\left(b - M\ \mathrm{Cos}\ \frac{\theta}{2}\right)\right] \qquad \textbf{(59)}$$

and at:

$$S_{3,4} = \frac{\omega_0}{2q}\left[\left(-a - M\ \mathrm{Sin}\ \frac{\theta}{2}\right) \pm j\left(b + M\ \mathrm{Cos}\ \frac{\theta}{2}\right)\right] \qquad \textbf{(60)}$$

where:

$$M = \left[(4q^2 - a^2 + b^2)^2 + 4a^2b^2\right]^{1/4} \qquad \textbf{(61)}$$

and:

$$\theta = \mathrm{Tan}^{-1}\left(\frac{2ab}{4q^2 - a^2 + b^2}\right) \qquad \textbf{(62)}$$

For high q applications, M approaches 2q and θ approaches zero. **Eq. 59** and **60** reduce, then, to the following approximations:

$$S_{1,2} = \omega_0\left[-\frac{a}{2q} \pm j\left(1 - \frac{b}{2q}\right)\right] \qquad \textbf{(63)}$$

$$S_{3,4} = \omega_0\left[-\frac{a}{2q} \pm j\left(1 + \frac{b}{2q}\right)\right] \qquad \textbf{(64)}$$

This bandpass transformation is illustrated graphically in **Fig. 15**.

Putting theory into practice

The portion of **Eq. 56** that comes from the ith lowpass pole pair is

$$A_i(s) = \frac{p_i p_i^* \left(\frac{\omega_0}{q}s\right)^2}{\left(s^2 + p_i\frac{\omega_0}{q}s + \omega_0^2\right)\left(s^2 + p_i^*\frac{\omega_0}{q}s + \omega_0^2\right)} \qquad \textbf{(65)}$$

This can be rewritten as:

$$A_i(s) = \frac{(a_i^2 + b_i^2)\left(\frac{\omega_0}{q}s\right)^2}{(s - s_a)(s - s_a^*)(s - s_b)(s - s_b^*)} \qquad \textbf{(66)}$$

where s_a and s_b are given by **Eqs. 55** and **56**. $A_i(s)$ can be factored into $A_a(s)$ and $A_b(s)$ such that:

$$A_a(s) = \frac{\frac{\omega_0}{q}(a_i^2 + b_i^2)^{1/2}s}{(s - s_a)(s - s_a^*)} \qquad \textbf{(67)}$$

and:

$$A_b(s) = \frac{\frac{\omega_0}{q}(a_i^2 + b_i^2)^{1/2}s}{(s - s_b)(s - s_b^*)} \qquad \textbf{(68)}$$

These sub-functions each can be implemented with a 2-pole active bandpass stage, **Fig. 4**, Part 1. At $s = j\omega_0$ **Eq. 65** equals unity. The combined gain of the two active stages used should thus be adjusted to one at $\omega = \omega_0$. This will insure unity amplitude response when all stages are cascaded to produce the transfer function of **Eq. 56**.

The design procedure for a specific bandpass filter is as follows. First, locate the poles of the corresponding lowpass prototype. Either pick the center frequency and bandwidth, or pick the cutoff frequencies and use **Eqs. 53** and **54** to compute the necessary center frequency and bandwidth. **Eq. 58** will provide the location of the bandpass poles corresponding to the real lowpass pole. Implement these poles with a 2-pole active bandpass stage, adjusting the gain at $\omega = \omega_0$ to unity. Use **Eqs. 59**, **60** or **63** and **64** to obtain the location of the four bandpass poles corresponding to each complex conjugate lowpass pole pair. Implement the bandpass response corresponding to the i^{th} lowpass pole pair with two cascaded active bandpass stages. Then adjust the combined gain of these stages to one at $\omega = \omega_0$. After implementing each required 2- and 4-pole filter section, cascade these sections in any order to achieve the bandpass response of **Eq. 56**.

This series has bridged the gap between the usual college level understanding of pole-zero analysis and the realization of complex active filter circuits. We have discussed some common filter types, and presented design techniques useful in their implementation. These techniques will produce a first-cut circuit that provides the desired frequency response. Further simplification or optimization of the circuit may be possible and is left to the reader. ☐

References

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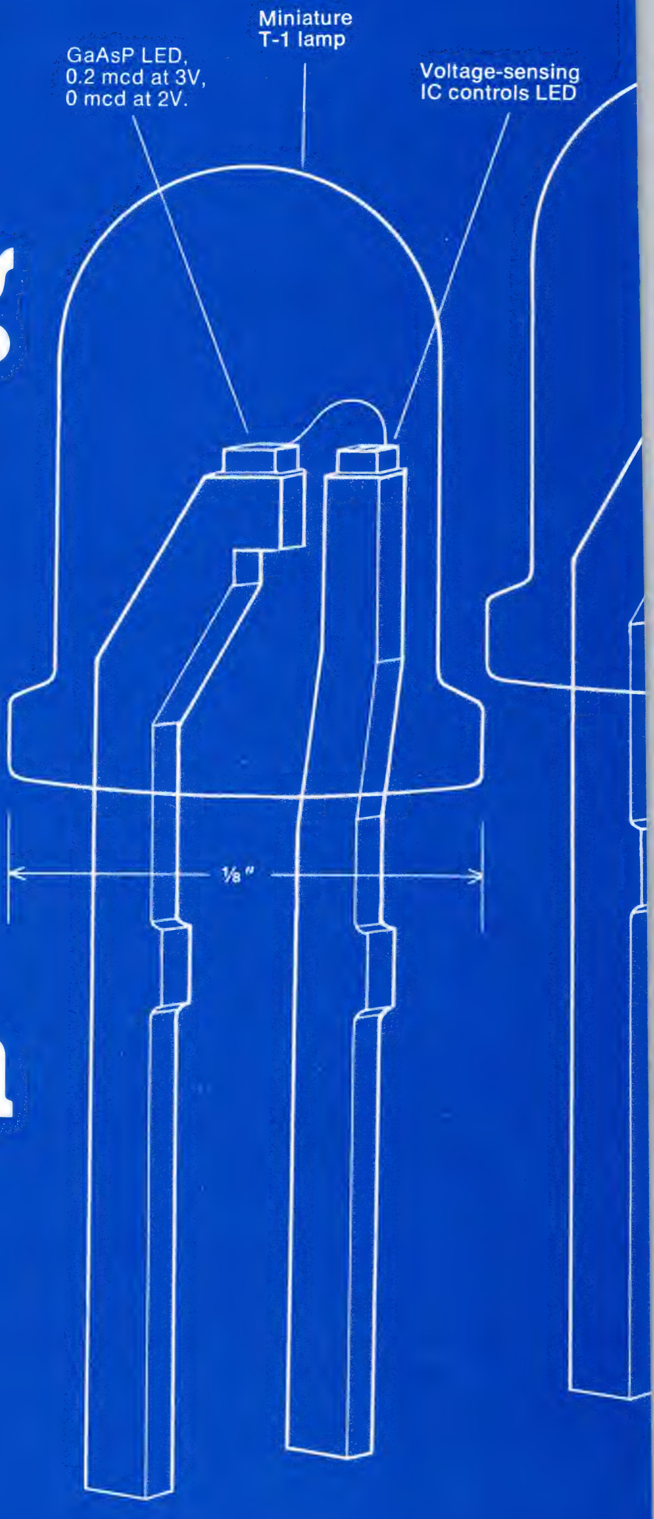

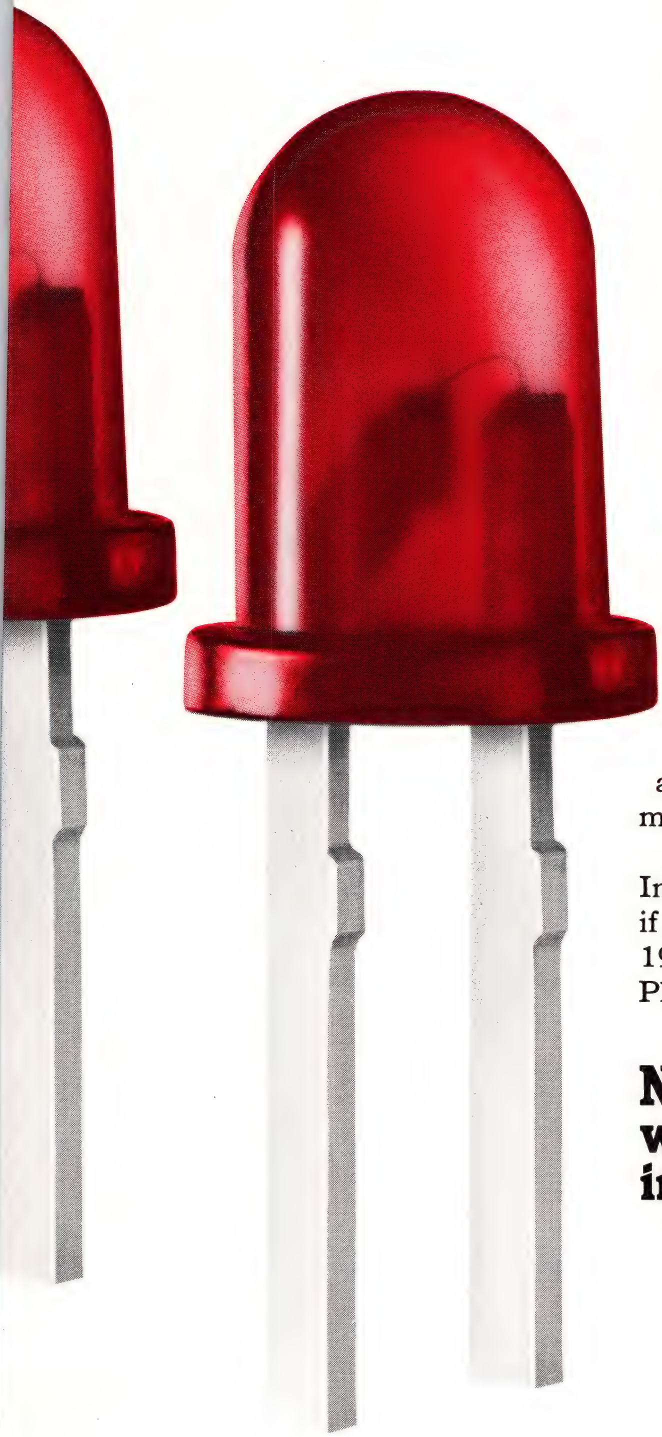

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Simple 10 kHz V/F features differential inputs

W. S. Woodward
University of North Carolina, Chapel Hill, NC

Voltage-to-frequency converters have long been a popular basis for analog-to-digital conversion and telemetry. In the former application, the combination of a V/F with a suitable time base and counter results in an inherently integrating and, hence, highly noise-immune digitizer. In telemetry systems, the serial output of the V/F is appealing.

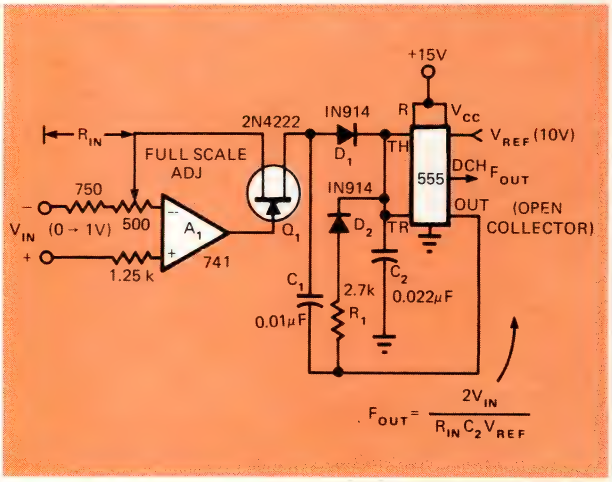
This simple circuit combines the popular 555-type IC timer with an op amp and a handful of discretes to yield a versatile system component. Salient features include better than 0.05% linearity over 3 decades (10 Hz to 10 kHz), fully differential inputs, ratiometric capability, and an open-collector output compatible with any positive-logic family (e.g., TTL, CMOS and HTL).

The central principle of operation is a variation upon the well-known "charge-dispensing" technique in which a current proportional to an input voltage is balanced via the periodic charging of a capacitor to a precisely repeatable voltage.

Generation of a current sink exactly proportional to the input voltage in this circuit is performed by the op-amp/FET combination of A_1 and Q_1. The FET source-current linearly discharges the parallel combination of C_1 and C_2 until the voltage at the upper terminal of C_2 ramps below the 555 trigger potential ($\approx V_{REF}/2$). At this time, the 555's output terminal swings HIGH, uncoupling the current sink by reverse biasing D_1 and beginning the re-charge of C_2 via D_2 and R_1. This state persists until C_2 charges to the threshold potential of the 555 (V_{REF}). The output then falls, reverse biasing D_2, and replenishing (through D_1) the charge drawn from C_1 during the C_2 charging interval. In this manner, the circuit adds a quantity of charge equal to $C_2V_{REF}/2$ to the C_1, C_2 combination.

The frequency with which the cycle is repeated is given by $F_{OUT} = 2V_{IN}/R_{IN}C_2V_{REF}$, where R_{IN} is the resistance seen between the FET drain and the negative input terminal. This relation will hold up to a limit that, for this combination of component values, exceeds 15 kHz. With the values shown, the nominal scale factor is 10 kHz/V.

Input offsets are determined by the quality of the op amp used. With proper selection of the amplifier and lower resistance values in the input network, full-scale sensitivities in the millivolt range may be achieved with 0.1% accuracy. CMRR is independent of input resistors match and is limited only by the amplifier chosen, although CM voltage should not exceed ±2V. Notice that the effective input impedance for positive signals (negative input grounded) is determined by the follower-impedance of the op amp. Typically, this is many megohms.



Better than 0.05% linearity over 3 decades (10 Hz to 10 kHz) is achieved with this simple circuit. It also features ratiometric capability, output circuit versatility and an accuracy TL of 0.01%/°C. CMRR is limited only by input op amp, but CM voltage should not exceed ±2V.

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No table is needed to calculate logarithms in any base

Eric B. Arnold,
Haughton Div., Reliance Electric Co.,
Ann Arbor, MI

I offer an alternative to Grover H. Martin's algorithm deriving logarithms on a 4-function calculator (EDN, January 20, 1974, pg. 78). My method enables the user of such a calculator to calculate logarithms in any base to the full accuracy of instrument in use. The procedure can be executed relatively quickly, remembered easily, and does not require a table. It does, however, require a scratch pad and some sort of writing instrument, but the use of these is confined to only two numbers.

The method proceeds as follows:

1. Choose the base desired; denote with b. ($b \neq 1$, > 0)
2. Divide the number N, whose $\log_b$ is desired, by b repeatedly until the quotient lies between 1 and b. The number of divisions required to do this gives the characteristic c: $Q_0 = N/b^c$
   (If N is less than 1, multiply instead of divide; the characteristic now is the negative of the number of multiplications.)
3. Leave Q_0 in the calculator and put a . on the scratch pad with lots of space to its right. Then iterate the following sequence of steps for i = 0, 1, . . . until sufficient accuracy has been obtained.
   a. Square Q_i.
   b. To the right of the . or the last digit recorded to its right, record a 0 if $Q_i^2 < b$ and put $Q_{i+1} = Q_i^2 i$; or, record a "1" if $Q_i^2 \geq b$ and put $Q_{i+1} = Q_i^2/b$.
   c. Go back to (a) unless sufficient accuracy has been obtained.
4. As you may have guessed, you have calculated the mantissa of $\log_b N$ in binary. Convert any way you like; the method I normally use is given in the example.

The number of bits which must be obtained before converting to octal can be determined for a particular calculator in the following manner. First, produce the binary mantissas for an arbitrary number and its reciprocal, using the same base for both. Bit strings ideally should be the logical complements of each other. They will be until round-off errors destroy the significance of the calculation. Thus, to determine the maximum number of bits of significance, count those for which the complement relation is valid. There is obviously no point in obtaining more bits. For my 8-digit calculator, 27 bits are sufficient.

If your calculator wastes one digit of display on a zero to the left of the decimal point when the result is less than 1, an extra digit in the mantissa can be obtained when converting from octal to decimal by dividing by 0.8 instead of 8 in the last step. Then shift the decimal point of the result one place to the left.

Since this method computes logarithms in any base, ln N can be obtained if desired. It may be simpler, however, to use the relation $\log_a X = \log_b X / \log_b a$, choosing a base b which is convenient for calculation (e.g., 2 or 3), then calculating $\log_b a$ as well as $\log_b X$ to obtain $\log_a X$. This avoids having to re-enter the 8-digit base a large number of times.

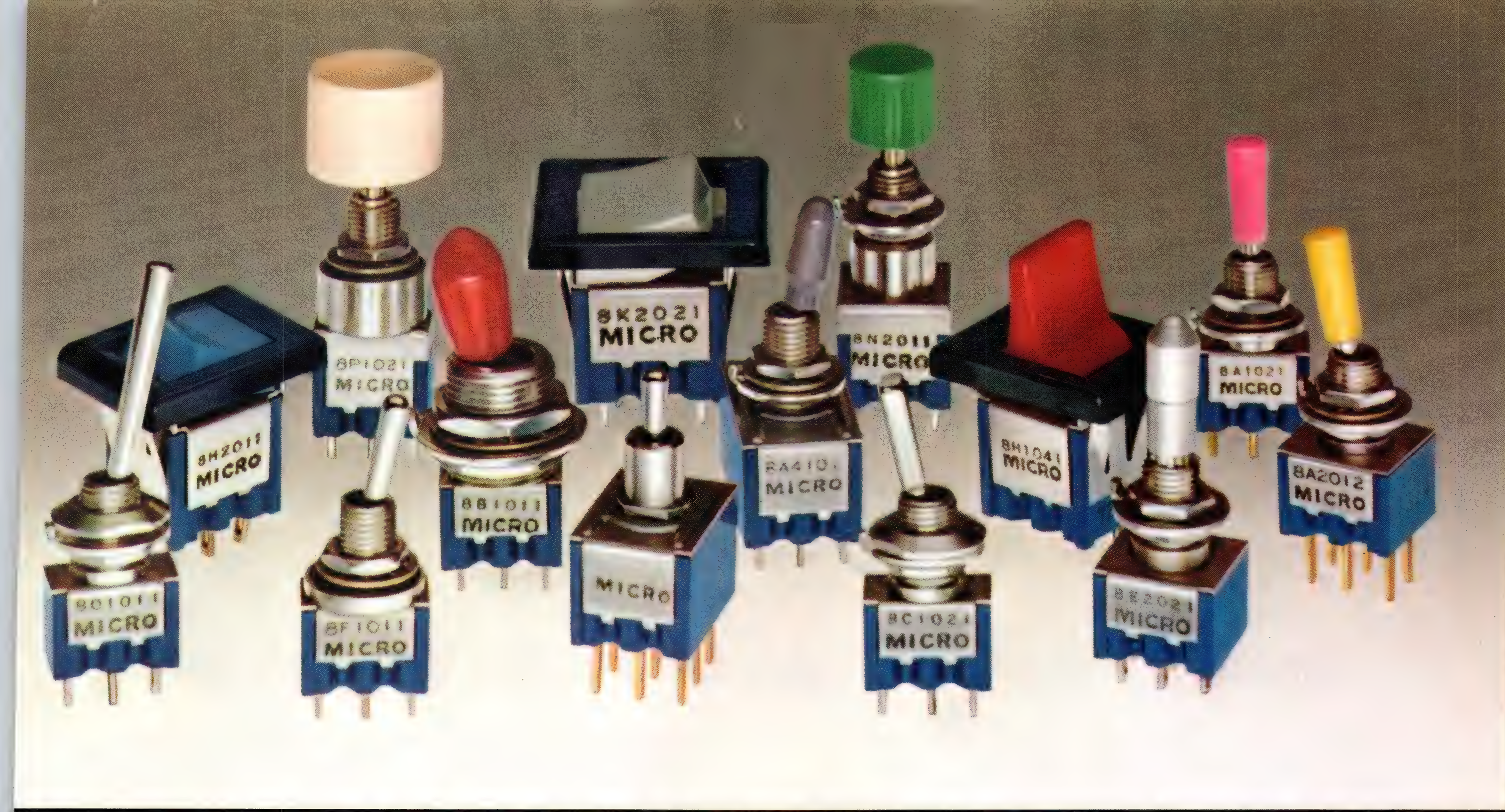
It is highly recommended that the reader develop the logic behind this approach, since it will make the procedure extremely easy to remember, even after months of not using it.

EXAMPLE: N = 361, b = 10

This gives $Q_0 = 3.16$, c = 2, since $361/10^2 = 3.61$ (This is written out here for instructive purposes only. In actual practice, the calculator retains all necessary numbers except the binary mantissa. The binary mantissa is the only part that the user has to record on his scratch pad. Calculations for this example were performed on a Bowman Model 905 calculator.)

i	Q_i	Q_i^2	RECURRENCE RELATION	ith bit
0	3.61	13.6321	$Q_{i+1} = Q_i^2/10$ (a)	1
1	1.30321	1.6983563	$Q_{i+1} = Q_i^2$ (b)	0
2	1.6983563	2.8844141	(b)	0
3	2.8844141	8.3198447	(b)	0
4	8.3198447	69.219815	(a)	1
5	6.9219815	47.913827	(a)	1
6	4.7913827	22.957348	(a)	1
7	2.2957348	5.2703982	(b)	0
8	5.2703982	27.777097	(a)	1
9	2.7777097	7.7156711	(b)	0
10	7.7156711	59.53158	(a)	1
11	5.953158	35.44009	(a)	1
12	3.544009	12.559999	(a)	1
13	1.2559999	1.5775357	(b)	0
14	1.5775357	2.4886188	(b)	0
15	2.4886188	6.1932235	(b)	0
16	6.1932235	38.356016	(a)	1
17	3.8356017	14.71184	(a)	1

Starting at the top of the bit column, we obtain the mantissa of $\log_{10} 361$ in binary: $M = \log_{10} 3.61 = (0.100011101011100011\ldots)_2$. This must be converted to decimal. A quick way to do this involves



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conversion to octal first, which can be done by inspection if the following binary-to-octal conversion codes are known:

Binary:	000	001	010	011	100	101	110	111
Octal:	0	1	2	3	4	5	6	7

Each octal digit corresponds to three binary digits (bits). Conversion to octal is achieved by dividing the binary number into groups of three bits starting at the left:

$$M = (0.100\ 011\ 101\ 011\ 100\ 011\ \ldots)_2 = (0.435343\ \ldots)_8$$

$$4 \quad 3 \quad 5 \quad 3 \quad 4 \quad 3$$

Conversion to decimal can now be done quickly on the calculator, starting with the right-most octal digit (3): Enter it in the calculator, divide by 8, add the next digit (4), divide by 8, add the next digit, divide by 8, etc., until the left-most digit has been added and the result divided by 8. This is the desired mantissa, good to about five decimal places: $M = 0.55750\underline{65}$. The last two places are somewhat uncertain because we terminated our binary mantissa at 18 digits, corresponding to six octal digits. This corresponds to a maximum possible error less than $1 \times 8^{-6} \simeq 0.0000038$. For greater accuracy, a larger number of bits can be obtained. □

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Circle 160

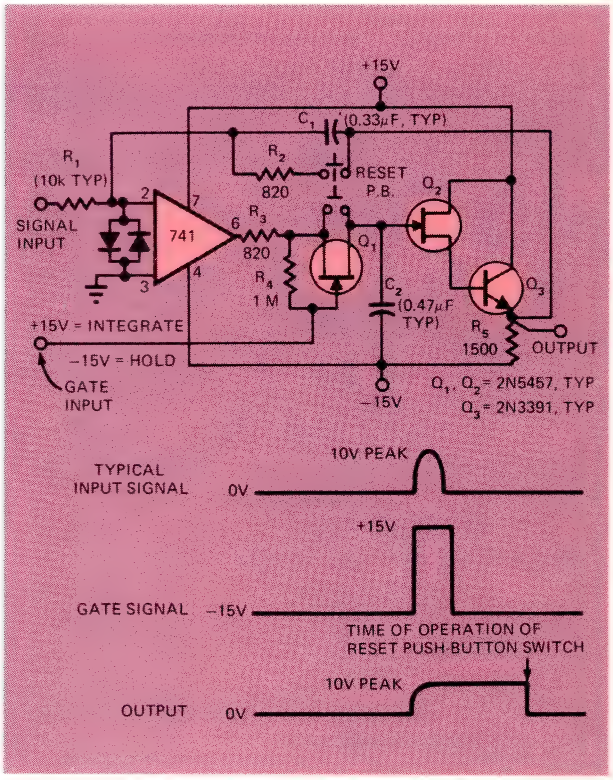
Circuit combines integrate, sample and hold functions

Edward Crovella,
Cardiac Electronics Inc., Clarence, NY

A sample and hold circuit is frequently used to temporarily store the output of an integrator. This circuit (**Fig. 1**) combines integrate, sample and hold functions, reducing such total circuitry by typically 40%. Essentially it is a version of a sample and hold circuit with capacitor feedback. The switching waveforms show circuit operation.

On the schematic, R_1 and C_1 are determined by the integrator scaling desired. The high limit on the size of C_2, the memory capacitor, is set by the fact that its charge time-constant through R_3 and Q_1 should be small compared to the time during which the amplifier is gated on. The low limit is determined by the fact that any small gate-to-drain leakage current in Q_2 charges C_2, thus basically determining long-term hold stability.

For most applications, a 741-type op amp proves satisfactory as the integrating amplifier. However, for critical applications, a FET-type is recommended. □



Total circuitry is reduced by about 40% when this modified sample/hold circuit with capacitive feedback is used to combine the integrate, sample and hold functions. Switching waveforms show operation.

To Vote For This Circuit
Circle 161

An analog multiplexer makes an ideal CMOS output driver

Victor Lilley and **Robert L. Rook**
Philco Ford, Newport Beach, CA

Faced with a requirement to make additions to the discrete-transistor 0/−6V logic of some analog computers, we chose quiet, voltage-compatible CMOS. In this application, V_{dd} pins were wired to ground while V_{ss} was supplied from an existing −6V power bus. NOR gates thus became NAND gates, and flip-flops triggered on the clock's trailing edge in accordance with the negative-true

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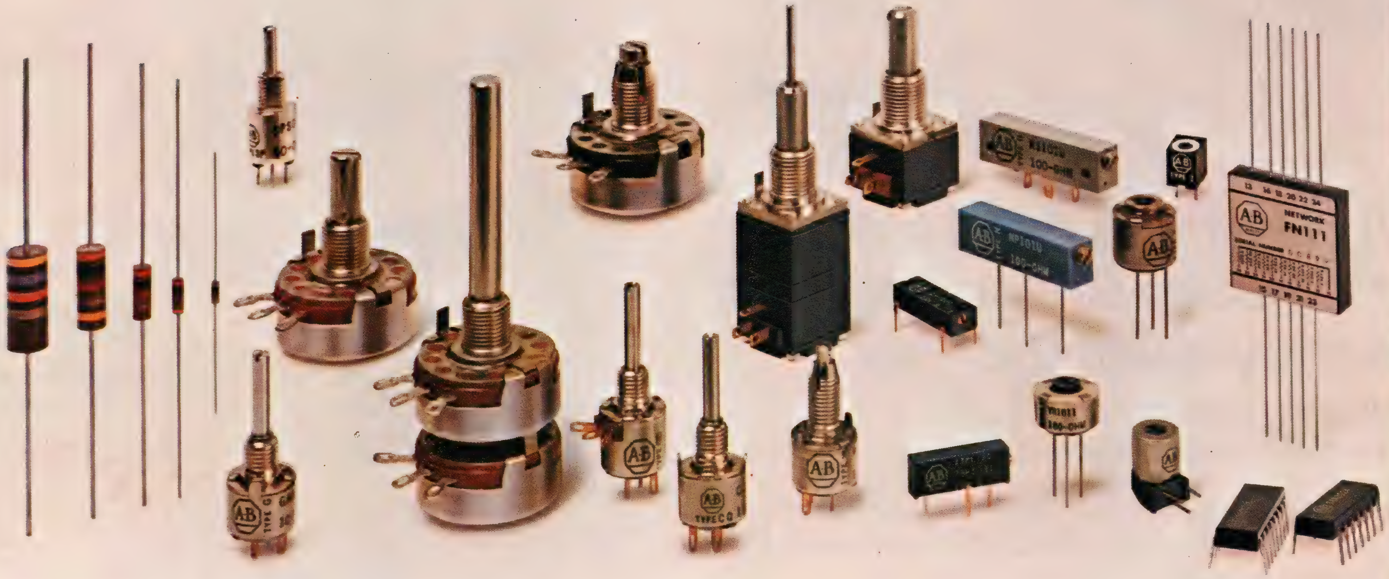
There's more to resistors than resistance



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"We learned the hard way. The subtle things make the difference. They all add up to the top quality we want in our products."

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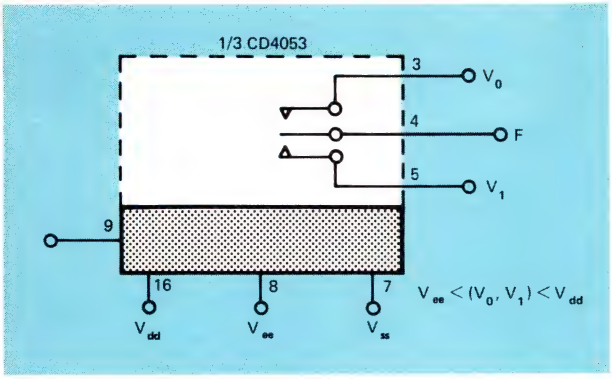

Fig. 1—This universal connection provides fully isolated translation to users choice of logic levels.

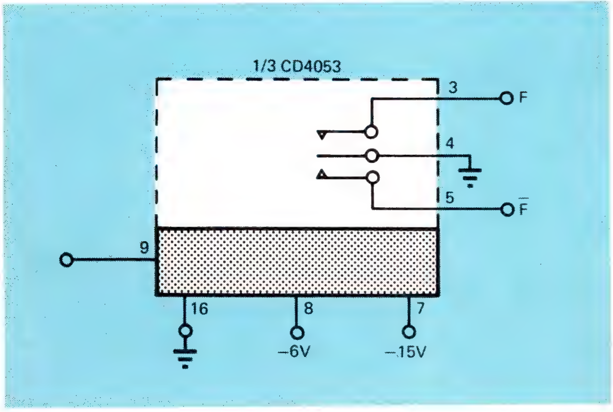

Fig. 2—Complementary (true/false) outputs are provided in the connection used in the analog computer application. Typically, 14 discrete-component gate inputs can be driven per output.

convention. The only problem encountered arose when it was necessary to return signals to the discrete-component logic world. Voltage levels were right, but even type CD4049 "high current" drivers had inadequate current capacity. In fact, paralleling all six drivers of the hex package provided only a minimal fan-out capability.

The type CD4053 analog multiplexer proved to be the perfect CMOS output interface element. Used as shown in **Fig. 1**, it could provide level translation to any desired pair of logic levels (V_0 & V_1) lying in the range between V_{dd} and V_{ee}. In this application, however, advantage was taken of the fact that the discrete-transistor logic of the analog computer views an open circuit as a true signal. Therefore, the CD4053 could be connected as shown in **Fig. 2**, providing three sets of complementary (true/false) outputs per IC package. In a loading test, a randomly-chosen unit drove 14 discrete-component logic gate inputs per output. This performance represented a fan-out capability more than adequate for our particular task.

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Circle 162

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IC D/A converter surpasses hybrid and modular devices

PROGRESS IN SEMICONDUCTORS

What makes a product unique? The standard definition of singularity or "one of a kind" doesn't seem to fit in the electronics industry. Perhaps a more suitable definition would be if the product surpasses all its peers in what and how much it can do for the price. Analog Devices' AD562 seems to fit this criterion for a unique product.

The AD562 is an IC 12-bit D/A converter with max. error of ±1/4 LSB at 25°C. Let's stop and examine this statement.

Usually, to achieve accuracy over a wide range of temperature, hybrid and modular techniques are used. These processes increase the size of the converter. AD seems to have overcome temperature stability problems while retaining a small size. They also claim that their unit is more accurate vs. temperature than any other 12-bit D/A converter.

Unique design package

The package consists of two IC chips internally connected and mounted in a hermetically-sealed ceramic 24-lead DIP. Thermal heating is minimized by switching at the collectors rather than at the emitters. Identical constant-current transistors are not turned off and minimum thermal heating is accomplished. Thermal transients and the nonlinearities that result from them are reduced as the various bits are switched.

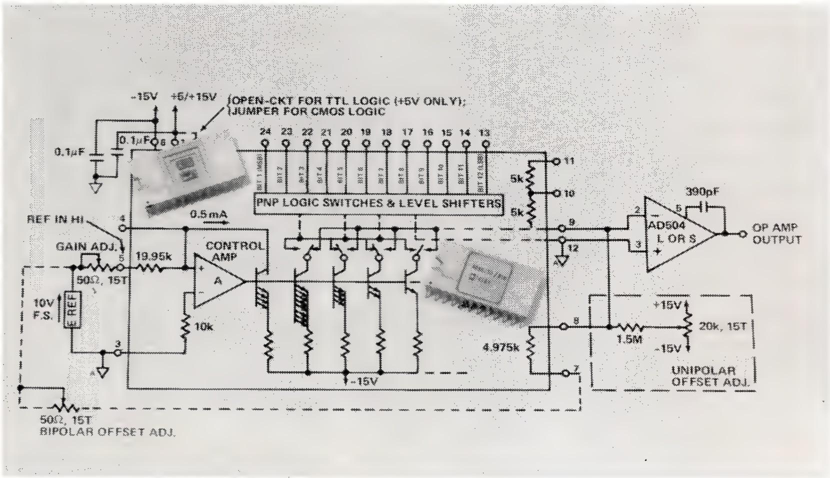

Fig. 1—Guaranteed monotonicity over −55 to +125°C is a key feature of Analog Devices' 12-bit Model AD562 D/A converter. Design highlights include a non-saturating current switching technique and a fully-differential precision current-switching cell structure.

The fully differential precision current-switching cell structure also provides increased immunity to supply-voltage variations. The power supply sensitivity of gain is kept below a maximum of 2 ppm of FSR/%. Since the collector voltage of the constant-current transistors does not change during bit switching, there is no differential power change in these transistors as various bit combinations are switched.

The four MSB constant-current emitter-ratio transistors are located on the axis of symmetry between each of their respective differential current switch pairs. As a consequence, the device is virtually free from nonlinearity and thermal transient errors attributable to differential heating effects.

Versatile inputs

In addition to having better gain and differential-nonline-

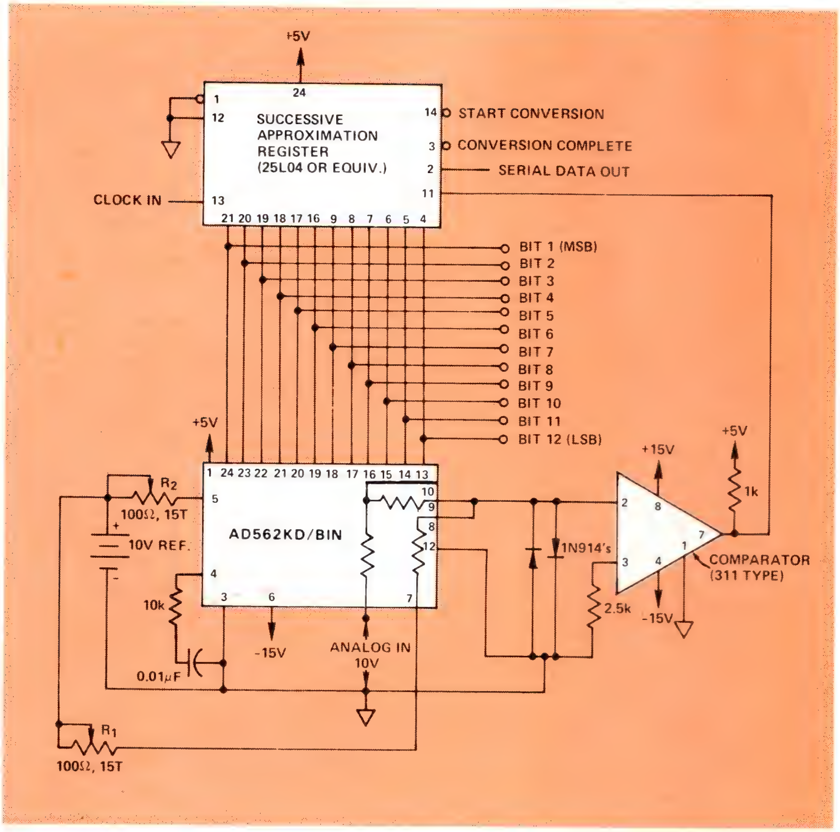

Fig. 2—A 40-kHz conversion rate for 12 bits is possible when the AD562 is used in this successive-approximation A/D converter design. It takes advantage of the 562's excellent accuracy and linearity, small size and low cost.

arity temperature coefficients (TC's) than those of modular or hybrid 12-bit DAC's, the AD562 has other performance features.

A unique input-circuit configuration provides true logic inputs that are fully compatible with TTL, DTL and both high and low-level CMOS logic. The same input-circuit design protects the AD562 from failures when active logic is applied prior to power-supply turn on. When used with a varying reference voltage, the AD562 becomes a 2-quadrant multiplying DAC.

And versatile outputs

The D/A is also moderately fast. It settles to ±1/2 LSB in less than 1.5 μsec with the addition of a single external resistor and capacitor. Available in versions for either binary or BCD input coding, the new DAC features two internal scaling resistors and an internal bipolar offset resistor. This resistor, when used with a suitable amplifier, allows the user to program five output-voltage ranges: 0 to 5V, −2.5 to 2.5V, 0 to 10V, −5 to 5V, or −10 to 10V. These internal scale resistors can also be used as terminating resistors when the AD562 drives the input of a comparator in applications such as the feedback element in a successive-approximation or tracking A/D converter.

The D/A converter is offered for operation over three temperature ranges. The AD562K, 0 to 70°C, is $58; AD562A, −25 to 85°C, $74; and AD562S, −55 to 125°C, $150. All prices are for 1-24 units.

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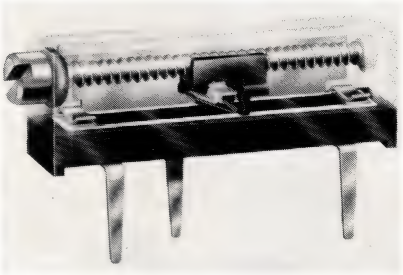

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28V SUBMINIATURE T-2 LAMPS FILL A GAP. They are available unbased, with wire leads (Model 6838), with submidget flange (Model 6839), or with bi-pin (Model 7839). Power required is 0.024A ±10%. Ratings include MSCP of 0.15 ±25% and average estimated life of 5000+ hrs. Model 6838 is 77¢(1000), Models 6839 and 7839, 97¢ (1000). Industrial Electronic Engineers, Inc., 7720-40 Lemona Ave., Van Nuys, CA 91405. Phone(213)787-0311. **Circle No. 172**

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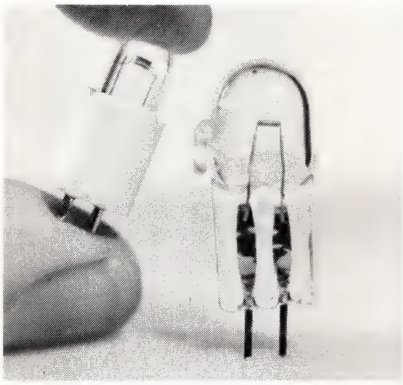

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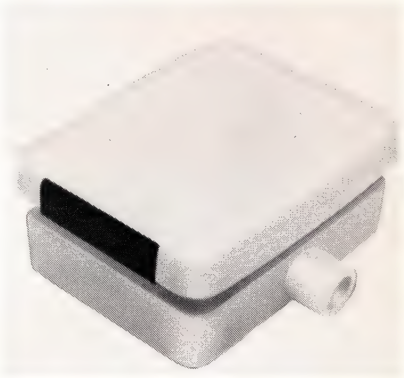

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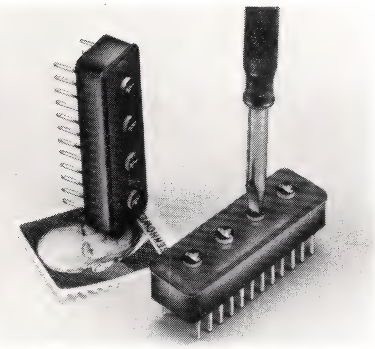

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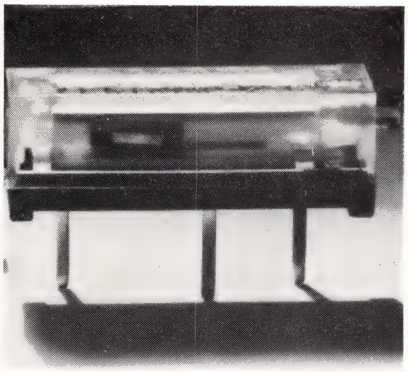

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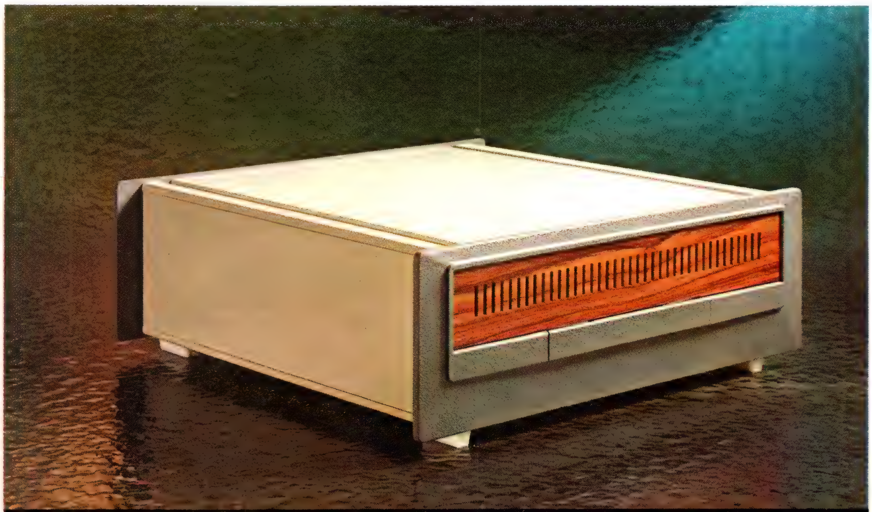

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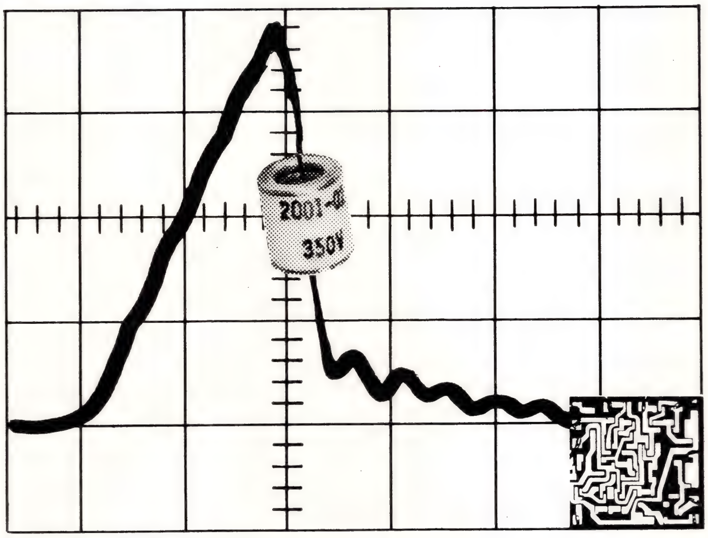

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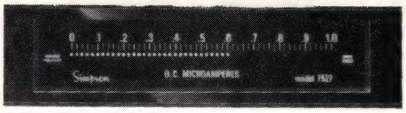

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Circle No. 185

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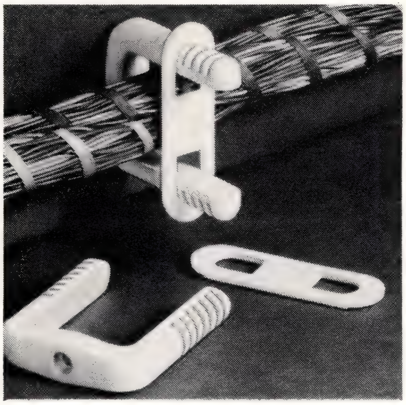
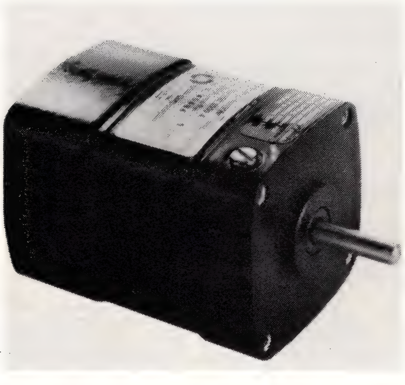


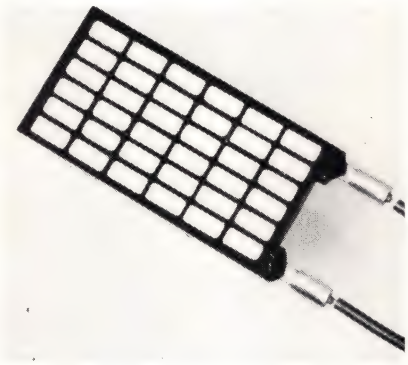
NYLON D-CLAMPS FEATURE POSITIVE LOCKING. This 2-piece nylon D-Clip provides a positive lock for wire and cable loads up to 1-in. high and 1/2 to 1-1/4-in. wide. The U-piece fastens with a single 3/16-in. flat head screw. After the bundle has been placed in the U-piece, the arms are compressed with fingertip pressure and a keeper piece is inserted against the bundle. Releasing the arms provides a positive lock. Free samples are available. Richco Plastic Co., 5825 N. Tripp Ave., Chicago, IL 60646. Phone(312)539-4060. **Circle No. 186**

1W CONDUCTIVE-PLASTIC POTS HAVE 1/4-IN. THICK BODY. Only 3/4-in. in dia. and rated 1W@70°C, Models 3851 and 3858 provide low contact resistance variation. Resistance range available is 1000 to 100,000Ω ±20%. Independent linearity is ±10% and rotational life is 100,000 cycles. These units meet or exceed MIL-R-94 requirements. 85¢ up (500). Bourns, Inc., 1200 Columbia Ave., Riverside, CA 92507. Phone(714)684-1700. **Circle No. 187**



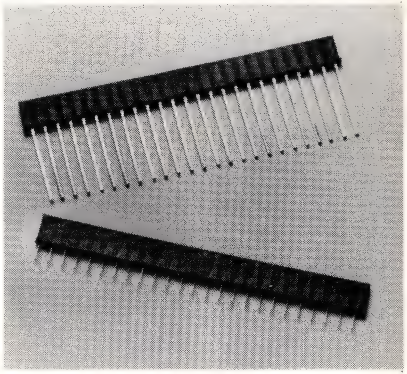
STEPPING MOTORS WITH 500, 720 AND 1440 STEPS/REV. ADDED to the HDM-150 Responsyn line. The 500 step/rev. motor is rated at 7.5 in. lb. torque, the 720 and 1440 step ones 10 in. lb. Max. stepping rates are 1500 steps/sec for the 4-phase, 720-step motor, 2000 steps for the 500-step one and 3000 steps for the 8-phase, 1440 step motor. Responsyn Products, Bldg. 3G, Sixth Rd., Woburn Industrial Park, Woburn, MA 01801. **Circle No. 188**

30-CONTACT PC-BOARD JOINER CARRIES 3A. Three-in. long and 0.098-in. sq, these sub-miniature right-angle pc-board joiners have 30 contacts on 0.100-in. centers. Their diallyl phthalate molded body has a temperature range up to 257° F. Contact tips are tin-plated, 0.02-in. in dia. by 0.145-in. long. 30-contact joiner, $2.79(100). National Connector, 9210 Science Center Dr., Minneapolis, MN 55428. Phone(612)533-3533. **Circle No. 189**



PELTIER MODULES PROVIDE ADJUSTABLE, REVERSIBLE COOLING. They generate a cold-face temperature of −15°C with the hot face held at +45°C when 9A are passed. A cooling power of 20W is obtainable from a Peltier element that measures 27.5 mm wide × 53 mm long × 4.5 mm thick and weighs 25g. Greater cooling power is gained by connecting modules in parallel thermally, but electrically insulated from hardware. $40. Jermyn, 712 Montgomery St., San Francisco, CA 94111. Phone-(415)362-7431. **Circle No. 190**

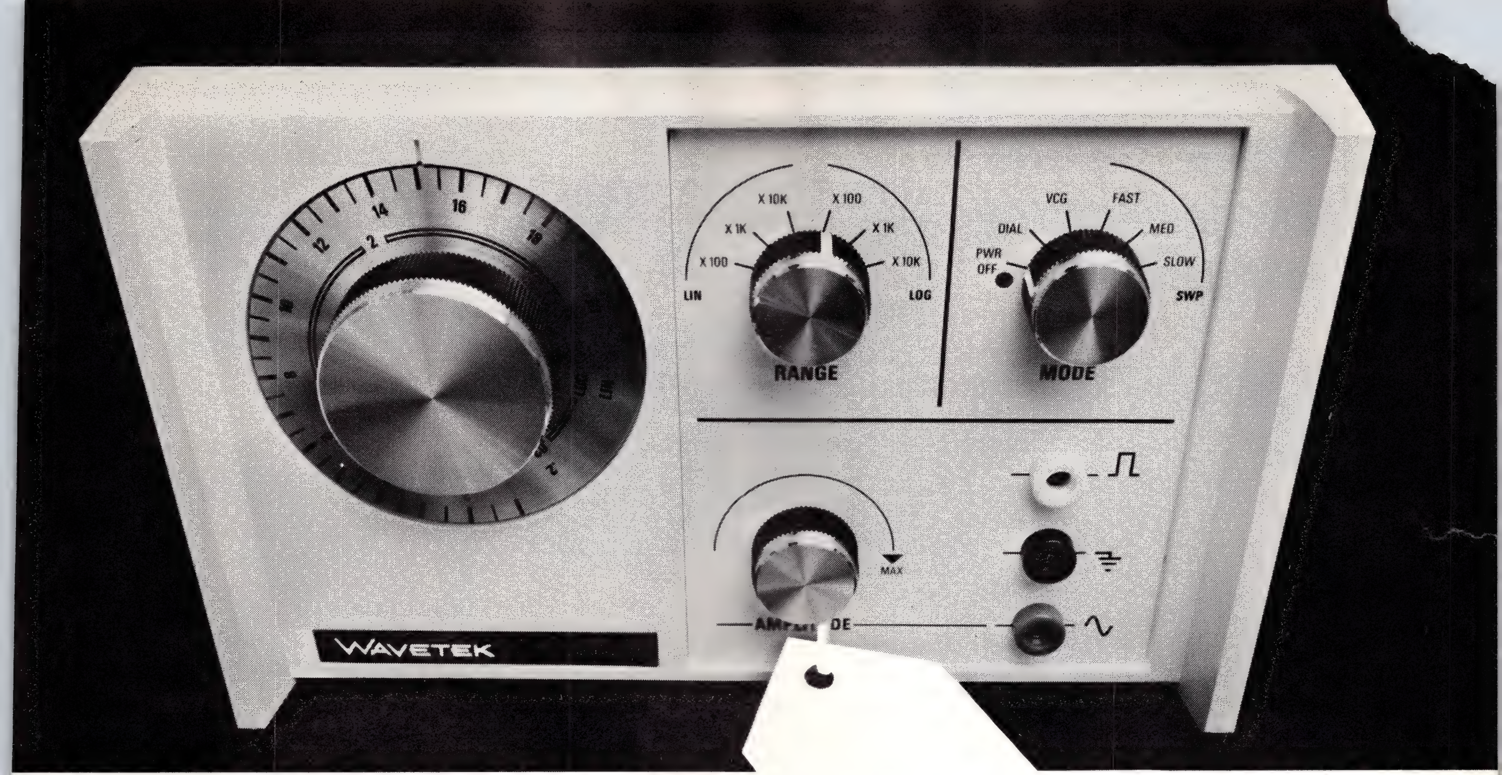
HAND TOOLS INSTALL FLAT CABLE CONNECTORS. Model 779-1000 installs flat cable to 14- and 16-pin DIP plug connectors, while Model 779-2000 installs both 14- and 16-pin DIP plugs and wrap-post transition connectors for cable widths of 20 to 50 conductors. A controlled cycle assures a positive connection every time; for once the cycle is initiated, the tool jaws cannot be opened until the full compression stroke is completed. 779-1000, $80; 779-2000, $140. Ansley Electronics Corp., 3208 Humboldt St., Los Angeles, CA 90031. Phone(213)223-2331. **Circle No. 191**



"SKINNY STRIP" SOCKET PROVIDES 25 CONTACTS SPACED 0.1 IN. Individual SB-25-100 strips are 25 contacts long, but may be cut or butted together without changing the 0.1-in. spacing. Their closed-entry, chamfered lead-in contacts are beryllium copper, plated with either gold or tin. Terminals are the solder-tab type and the body is glass-filled nylon. Robinson-Nugent, Inc., 800 E. Eighth St., Box 470, New Albany, IN 47150. Phone(812)945-0211. **Circle No. 192**

SOLDERLESS PC-BOARD CONNECTOR TERMINATES 50 CONDUCTORS. Blue Streak^R connectors are of 1-piece design. They are available in pin lengths to accommodate pc-board thicknesses of 0.031 to 0.094-in. A "tulip" contact design provides 4 contact points/conductor. Temperature rating is 105°C, current rating is 1A and dielectric strength is 1500V dc. The connectors are terminated to flat cable with 28-30 AWG solid wire or 28 AWG stranded wire. Ansley Electronics Corp., 3208 Humboldt St., Los Angeles, CA 90031. Phone-(213)223-2331. **Circle No. 193**

HV RESISTORS TO 2000 MΩ HAVE 0.1% LONG-TERM STABILITY. Type MG power film resistors employ Micronox^R resistance films to provide from 200Ω to 2000 MΩ. Thev can be operated continuously at voltages as high as 30,000V. One model, MG 815, will dissipate 15W in an encapsulated resistor measuring only 6 in. L × 3/8 in. dia. Typical full-load stability is 0.1%/1000 hrs. at 125°C. Delivery: samples in 3 working days, production quantities, 4 to 6 wks. Caddock Electronics, Inc., 3127 Chicago Ave., Riverside, CA 92507. Phone(714)683-5361. **Circle No. 194**



This Model 30 portable function generator goes from 2 Hz to 200 kHz with sines, squares, triangles, and linear or log sweeps.

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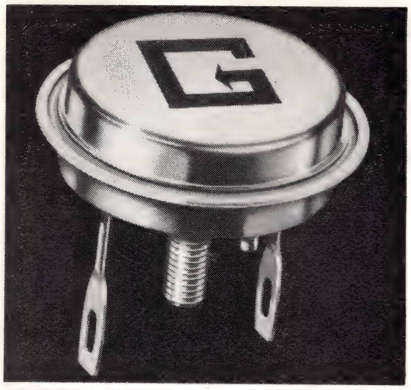
SEMICONDUCTORS



POWER TRANSISTORS HANDLE UP TO 80V. Packaged in TO-36 housings, the series contains five 12A germanium power transistors designated 2N173, 2N174 and 2N441-3. All are hermetically sealed and have applications in computer peripherals, communications equipment, audio amplifiers and battery operated equipment. $2 and $3. Germanium Power Devices Corp., Box 65, Shawsheen Village Station, Andover, MA 01810. Phone(617)475-5982.
Circle No. 195

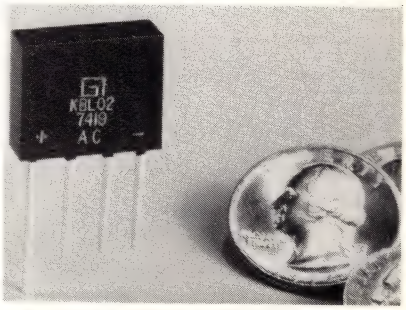
SCHOTTKY ARITHMETIC LOGIC UNIT OFFERS HIGH SPEED. This unit is designed as a pin-for-pin replacement for a like-numbered circuit originally offered by T.I. The AM54S/74S181 offers the handling of a 4-bit number in 9 nsec and a 16-bit number in 17 nsec. It has the capability of doing 16 arithmetic operations including add, subtract, double and compare. −55 to 125°C is $45(100); 0 to 70°C, $10(100). Advanced Micro Devices Inc., 901 Thompson Pl., Sunnyvale, CA 94086. Phone(408)732-2400.
Circle No. 196

STEP-RECOVERY DIODES FEATURE HIGH EFFICIENCY. Designed for use as high- and low-order harmonic generators, the diodes are available in a variety of packages. They have typical outputs of 0.3W from 10-20 GHz, and 6W in the 3 to 5 GHz range. Transition times range from 50 psec for the high-band units to 250 psec for the low-band ones. Model 5082-0805 through 0836, $39.85(1-9); 5082-0885(10-20 GHz), $43(1-9). Hewlett-Packard, 1501 Page Mill Rd., Palo Alto, CA 94304. Phone(415)493-1501.
Circle No. 197

GENERAL-PURPOSE OP AMPS JOIN FAMILY. Eight general-purpose IC op amps are offered as direct replacements for industry types 107, 207, 307, 101, 101A, 201, 201A and 301A. These dual-supply, high-input impedance types can be used in sample and hold, comparator, low-freq. waveform generator and summing amplifiers. CA307S, 52¢ (1000); CA101AS, $6.35(100). RCA Solid State Div., Box 3200, Somerville, NJ 08876. Phone(201)722-3200.
Circle No. 198

VISIBLE LED'S HAVE JEDEC REGISTRY. The IN5909 through IN5912 series includes red, green and yellow LED's. Operating and storage temperature range for the devices is −40 to 100°C. IN5909 and IN5910 are red-emitting GaAsP devices with 75° and 100° viewing angles, while IN5911 and IN5912 are green and yellow-emitting GaP diodes with 90° angle. Prices are 35¢, 37¢, 99¢ and 89¢ (100), respectively. Motorola, Box 20912, Phoenix, AZ 85036. Phone(602)244-6900. **Circle No. 199**

HYBRID OP AMPS OFFER HIGH-RELIABILITY AND POWER. HC2000H/1-4 are solid-state hybrids in metal hermetic packages. Rated at 100W and 7A, these devices are screened to 4 reliability levels that approximate MIL-STD-883. Operating from either single or split power supplies, the units employ a quasi-complementary class B output circuit with built-in load protection. HC2000H/1, $300(15-24); HC2000H/4, $125(15-24). RCA Solid State Div., Box 3200, Somerville, NJ 08876. Phone(201)722-3200. **Circle No. 200**



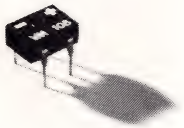
4-AMPERE BRIDGE RECTIFIERS FEATURE LOW COST. A unique flame-retarding material is used in the fabrication of these miniature 4A, 55 to 150°C silicon units. Rated at 50-800V PRV, with peak surge rating of 200A, they are designed for pc-board use. 85¢ (5000). General Instrument Corp., Semiconductor Components Div., 600 West John St., Hicksville, NY 11802. Phone(800)645-1247. **Circle No. 201**

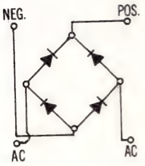
NEW DIB*

DUAL IN-LINE BRIDGE

An integrated bridge rectifier in a dual in-line package

ACTUAL SIZE PACKAGE





Another FIRST from Varo Semiconductor, Inc. An integrated bridge rectifier in a miniature, 4-pin, low-profile DIP.

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For simplified board layout the four leads are on 0.10" (2,54mm) grid spacing. The bridge can be used with standard DIP sockets.

Typical applications include electronic calculators, small permanent magnet motors (such as used in shavers and hair dryers), solid state relays and similar applications where full-wave rectification and small size is required.

Two DIB series are available: ½ Amp I_o at 55°C, (T_A) with 25V, 50V, 100V and 200V (V_{RRM}), and a 1 AMP I_o at 40° C , (T_A) with 50V, 100V, 200V, 400V, 600V, 800V and 1000V (V_{RRM}).

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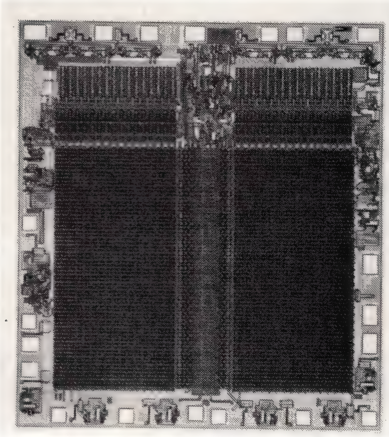
For more information, Circle No. 62



$12 BUYS A 4k RAM. The 2107A-8 is a silicon gate n-channel MOS RAM packaged in a 22-pin plastic or ceramic DIP with the industry standard pin configuration. Access, read and write cycle times are 420, 690 and 970 nsec, respectively. A fully decoded, single clocked, TTL-compatible design that operates on +5, −5 and +12V supplies, it allows a typical array of 32k bytes to operate at 4W average power. Intel Corp., 3065 Bowers Ave., Santa Clara, CA 95051. Phone(408)246-7501.

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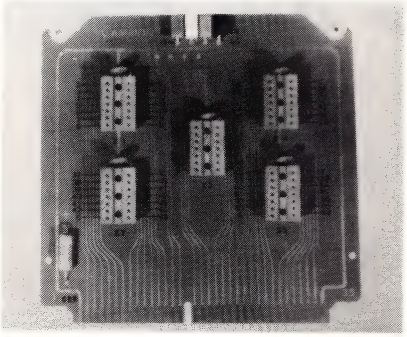
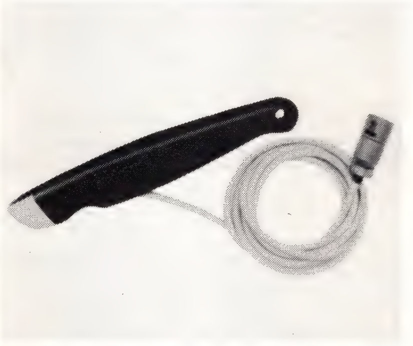


SOCKET LOGIC CARDS OFFER A VARIETY OF FEATURES. Four type 785 cards can mount either 14- or 16-pin DIP's in sets of 5 or 4, respectively. Common ground and power connections are selectable. All cards contain power supply and high-frequency bypass capacitors. These 4-1/2 in. cards fit in files 0.625 in. on center and are CMOS, MOS, TTL and DTL compatible. Colored test points have wire-wrap terminations. Cambridge Thermionic Corp., 445 Concord Ave., Cambridge, MA 02138. Phone(617)491-5400.

Circle No. 204

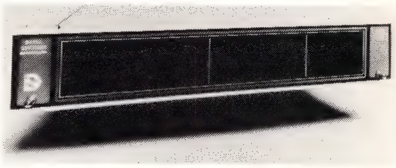


MAGNETIC WAND DISPLACES OPTICAL AND LASER SCANNERS. Especially designed for electronic cash registers, the model MW-500 magnetic wand is capable of reading both character and coded data that is pre-recorded magnetically (or stamped with magnetic ink) on sales slips, tags or cartons. Recording density is up to 300 bpi with a data transfer rate to 12,000 b/sec. $118.95. Advanced Magnetic Products, Inc., 7067-1/2 Vineland Ave., North Hollywood, CA 91605. Phone(213)764-4712.

Circle No. 205

PDP-11 USERS ARE NOW OFFERED A P103 SOFTWARE PACKAGE. The P103 9-program package—usable with a PDP-11 computer, 4k of memory, a teletype, and a CartriFile unit—is comparable to DEC programs on paper tape for high- or low-speed paper tape readers and punches. Except for the Cartrifile IOX routine, the package is supplied on cartridge tapes for CartriFile 10, 20, and 40 memory systems. ASCII source tapes are also available. $250. Tri-Data Corp., 800 Maude Ave., Mt. View, CA 94040. Phone(415)969-3700.

Circle No. 206



DISTRIBUTION SYSTEM HANDLES 32 CHANNELS OF ANALOG DATA. The DDS-32 is a D/A conversion and distribution system. It presents a stored 8-, 10- or 12-bit data word as an analog signal to an address-selected output channel. Settling time is 2 μsec to ±0.0025% of F.S., and analog output is unipolar or bipolar at 5 or 10V with a ±10 mA drive. Unit height is 3-1/2 in. and operation is 47 to 63 Hz, 115/230V. $1360. Datel Systems, Inc., 1020 Turnpike St., Canton, MA 02021. Phone(617)828-8000.

Circle No. 207

VIDEO INVERSION TELLS IF DATA IS FIXED OR VARIABLE. The Model 4011 video terminal edits with a standard keyboard plus a numerical-key cluster. Its display capacity is 1728 characters (27 lines with 64 cpl), and numerical entries are automatically right justified. The terminal can be hardlined up to 2000 ft. or remoted via phone lines. It provides control for a printer echo of CRT or computer input data. $5950. Qantel Corp., 3525 Breakwater Ave., Hayward, CA 94545. Phone(415)783-3410.

Circle No. 208

HIGH-SPEED MULTIPLEXER USES 8080 μP. The MicroPac RT multiplexer harnesses the Intel 8080 micro CPU for use as a remote industrial terminal. MicroPac RT is to be installed next to the process with which it is connected and is able to interface with any analog or digital instrumentation. Because of the multiplexing function of the micro CPU, the MicroPac RT can communicate with any central computer via coax or twin-ax cable. This saves up to 50% in cabling costs. Process Computer Systems, G-4025 S. Center Rd., Flint, MI 48507. Phone(313)744-0225. **Circle No. 209**

MULTIPLEXER IS ASYNCHRONOUS; SPEED AND CODE TRANSPARENT. The TDM-700 transparent digital multiplexer accepts up to 204 low-speed asynchronous signals from teleprinters and/or other data sources. Using time-division multiplexing and transition encoding, inputs are multiplexed into a synchronous high-speed output of 54 or 64k bps. The output interface can be a 56k bps modem, T-1 multiplexer, or 56k bps bipolar cable driver/receiver. Comtech Laboratories Inc., 135 Engineers Rd., Smithtown, NY 11787. Phone(516)231-5454. **Circle No. 210**

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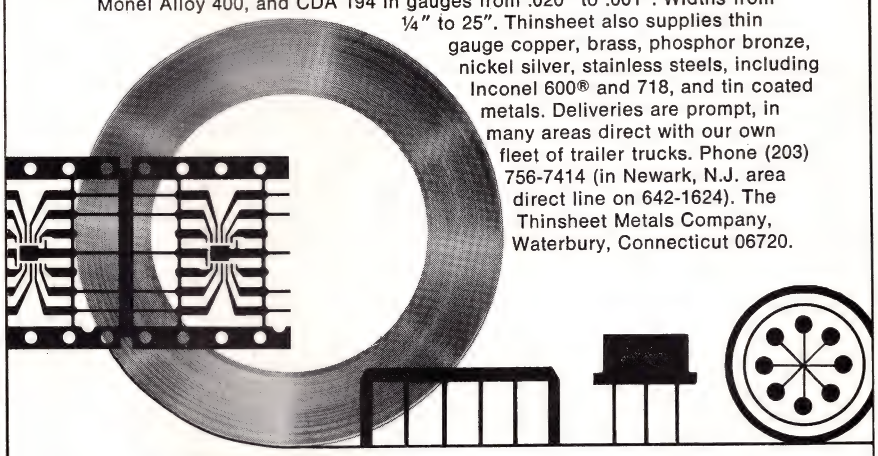

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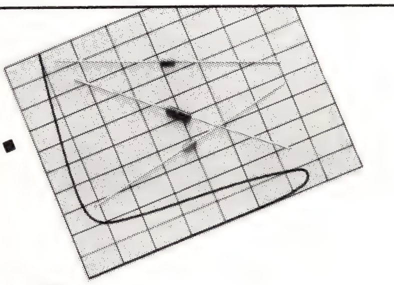

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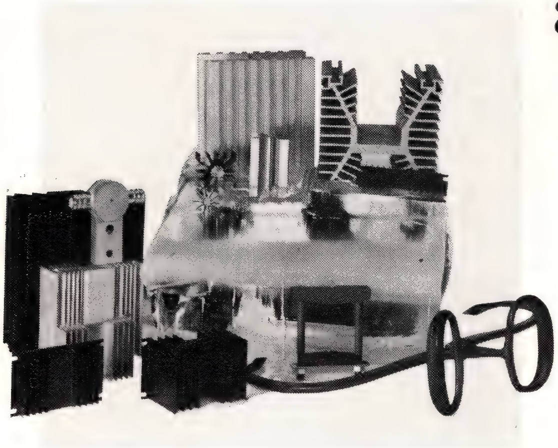

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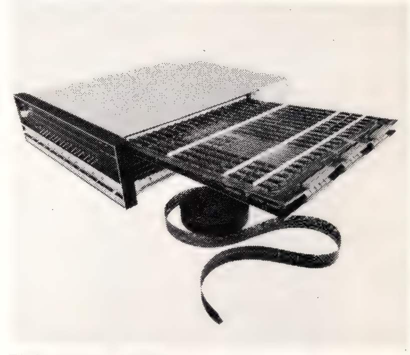
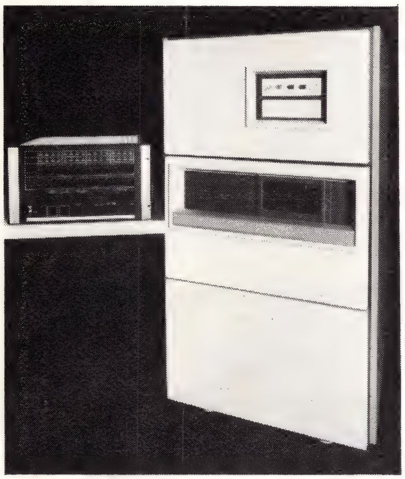
For more information, Circle No. 66



FLOATING-POINT SYSTEM EMULATES NOVA FORTRAN 5. FPS "faster" Fortran IV for Nova users is an integrated hardware/software package. Its FP-09 processor is a 2-piece card arithmetic unit built with monolithic TTL IC's for the microprogrammed instruction set. The run-time library includes symbol redefinition plus 94 subroutines that provide speedy computations for all functions known to Fortran 5. Delivery is 60 days ARO. $4500 (plus $500 for software). Floating Point Systems, Inc., 3160 S.W. 87th Ave., Portland, OR 97225. Phone(503)297-3318. **Circle No. 211**

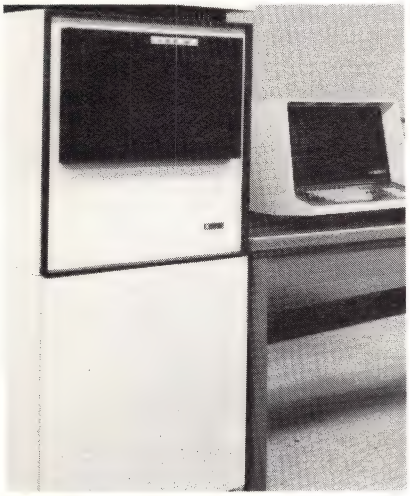
"DO IT YOURSELF" ADD-ON MEMORY FOR IBM 360/25 USERS. The 360/CORE 25 memory consists of a series of simple-to-use modules that enable nontechnical computer operators to perform installation, expansion, testing, maintenance and repair of their System/360 Model 25 processor memories. The modules are available in memory sizes of 16k, 24k or 32k bytes. 360/CORE 25 is packaged in plug-in modules. Delivery, 90 days ARO. $36,000. Cambridge Memories, Inc., 12 Crosby Dr., Bedford, MA 01730. Phone(617)271-6300. **Circle No. 212**

SPEED UP YOUR DEVELOPMENT OF MICROCOMPUTER SOFTWARE. The L Series high-speed punched tape reader provides for faster loading of programs and reading of source and other tapes. The LHR reads 5-, 6-, 7- or 8-level paper and paper-polyester or metallized polyester tape, fan-fold or rolled, at 200 cps. (20× faster than an ASR33 reader). Complete electronics are included for interfacing to L Series computers, with direct plug-in to new enclosures, or wiring into older models. Control Logic Inc., 9 Tech Circle, Natick, MA 01760. Phone(617)655-1170. **Circle No. 213**



MICROPROGRAMMED DISC SYSTEM SETS COST/PERFORMANCE RECORD. This low-cost disc drive system with a microprogrammed controller for minicomputers provides reprogramming capability with self-run diagnostics for large capacity, high-speed random-access mass storage. Over 116 million 8-bit bytes of data can be stored on each disc drive unit and 4 drives are handled by 1 controller. Delivery is 60 days ARO. $19,000. Pico, 1616 S. Lyon St., Santa Ana, CA 92705. Phone(714)835-0465.

Circle No. 214

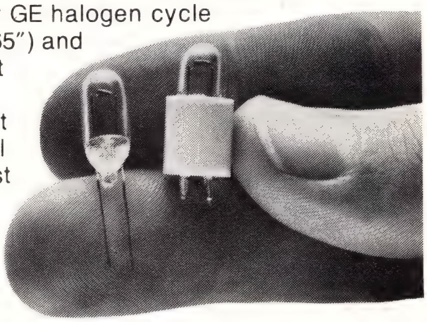


TAPE SYSTEM HANDLES 7 DATA-COLLECTION TERMINALS. Model 8090 magnetic tape pooler enables local and remote data-collection terminals to generate industry-compatible magnetic tapes for computers. It also can read and transmit magnetic-tape data generated by a computer to the data collection terminals. A CRT display with keyboard gives operator control. Monthly lease is $496 to $545. $17,440. Sanders Data Systems, Inc., Daniel Webster Hwy. S., Nashua, NH 03060. Phone(603)885-3727.

Circle No. 215

New and improved General Electric lamps provide for increased design flexibility.

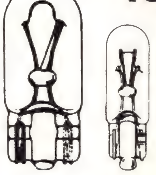
Two new sub-miniature halogen cycle lamps ideal for miniaturization.



These new T-2, 6.3V, 2.1 amps, 75 hour GE halogen cycle lamps are the smallest of their type (.265") and set industry standards for size and light output (16-20 candlepower). They are perfect for miniaturization of equipment such as reflectors, housings and optical systems. They also save on overall cost of equipment and are less than half the cost of the #1973 quartz lamp they replace.

Two terminal configurations are available. #3026 (20 candlepower) has wire terminals. #3027 (16 candlepower) has a new two pin, ceramic base that plugs in to make installation and removal a snap. Samples of the #3027 lamp are available in limited quantities now; production quantities will be available in the first quarter of 1975. These lamps have an iodine additive that creates a regenerative cycle that practically eliminates normal bulb blackening. They will produce approximately 95% light output at 75% of rated life.

An expanded line of Wedge Base Lamps for simple, low-cost circuitry.



Now you can have greater design freedom than ever before with wedge base lamps. GE now offers six large lamps in its line of T-1¾ (.230" max.) all-glass, sub-miniature wedge base lamps. In addition to our three 14V lamps (#37, #73 and #74), we now also offer two 6.3V lamps (#84 and #86) and a 28V lamp (#85).

These lamps are ideal for applications where space is at a premium. Their wedge-based construction allows you to design for low-cost sockets and virtually ends corrosion problems because they won't freeze in the sockets. And the filament, which is always positioned in the same relation to the base, offers more uniform brightness.

Green Glow Lamp has been improved over previous lamp.

Actual Size

Now our G2B Green Glow Lamp, the only domestic green lamp on the market today, gives a more uniform, purer green light than our previous model. It's bright enough for your circuit component applications. With appropriate current limiting resistors, it can be used for 120/240 volt green indicator service. Or used together with our high-brightness C2A red/orange/yellow glow lamps to emphasize multiple functions with color.

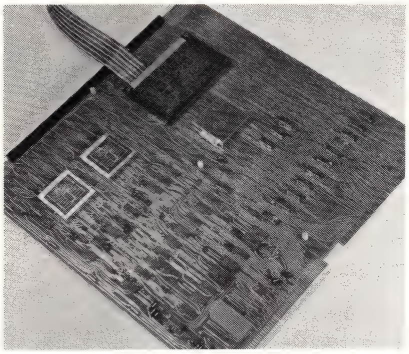
All GE glow lamps give the benefits of small size, rugged construction and low cost — 12¢ each for the G2B, 4.4¢ each for the C2A in 100,000 quantities.

Send today for newest literature.

For the most up-to-date technical information on any or all of these lamps, write: General Electric, Miniature Lamp Products Department, #0749-K, Nela Park, Cleveland, Ohio 44112.

GENERAL ELECTRIC

For more information, Circle No. 67



DATA ACQUISITION AND CONTROL SYSTEM UPS SAMPLE RATE. Model 500-DGC plugs into one slot of the mainframe of any Nova or Supernova minicomputer. The unit has up to 64-channel multiplexer capability. It contains a high-speed sample and hold, a 12-bit ADC, 2 12-bit DAC's and a program interrupt I/O interface that connects to the minicomputer bus. Channel-to-channel sampling rates of 100,000 samples/sec possible. $1800 (16 channel), $1990 (32 channel). ADAC Corp., 29B Cummings Park, Woburn, MA 01801. Phone (617)935-6668.

Circle No. 216

SEQUENCE CONTROLLER PROVIDES HIGH PERFORMANCE AT LOW COST. Model 1033 is designed to periodically connect the ac line voltage to as many as 16 different loads for controlled periods of time. Current requirements of the load can range up to 8A. Card-mounted controls set the duration of load energization and the rate at which the load is pulsed. Operating temp. range is −55 to +125°C. $130, with delivery of 2-4 wks. ARO. Libra Systems Corp., 1055 W. Germantown Pike, Fairview Village, PA 19409. Phone(215)631-0900.

Circle No. 217

AMP DESIGNED FOR LINE-OF-SIGHT COMMUNICATION SYSTEMS. Delivering 1W min. at 7725-8275 MHz, the VCM-5004 incorporates a power output monitor, self contained input-output circulators and current regulators. NF rating is 33 dB, gain 27 dB min., phase linearity ±2°/40 MHz and amplitude linearity ±0.2 dB/40 MHz. Operating temp. range is 0 to 55°C. Raytheon Co., 130 Second Ave., Waltham, MA 02154. Phone(617)890-8080. **Circle No. 218**

HIGH-POWER AMP FEATURES REPLACEABLE MODULES. Operating over the frequency band of 1750 to 1850 MHz, the PWA 1718-12 delivers 132W of saturated output power. Features include 50-dB gain, output circulator for protection against load mismatches and stripline and MIC construction. Dc input is +28V at 19A max. Input and output connectors are SMA type N female. Microwave Power Devices, Inc., Adams Ct., Plainview, NY 11803. Phone (516)433-1400. **Circle No. 219**

MINIATURIZED RF FILTERS HANDLE PC-BOARD APPLICATIONS. The TSC filters are 0.1-dB Chebyschev fixed-frequency types, with center frequencies from 40 to 500 MHz and bandwidths from 1 to 5%. They can handle up to 5W average input power (30W, peak). Typical figure for insertion loss is 1.4 dB for a 10% bandwidth, 4-section unit at 250 MHz. $195-$300. Telonic Altair, 21282 Laguna Canyon Rd., Laguna Beach, CA 92652. Phone(714)494-9401.

Circle No. 220

Dynamic Measurements Corp.
VOLTAGE TO FREQUENCY CONVERTER
821 A
Dynamic Measurements Corp.
VOLTAGE TO FREQUENCY CONVERTER
801 A
Dynamic Measurements Corp.
VOLTAGE TO FREQUENCY CONVERTER
811 A

VOLTAGE/FREQUENCY CONVERTERS ARE LINEAR TO BELOW 1 mW. All VFC models come in A, B or C versions with gain TC of 20, 10 and 5 ppm, respectively. Models 820 through 823 draw under 26 mW. They have 1-kHz and 10-kHz output freq. for 5V or 50 μA inputs with 0.01% linearity guaranteed down to 0.5 mV or 5 nA. The 830 series has high-impedance inputs with 80 dB CMRR. F.S. output with 10V input is 40 kHz, with linearity of 0.01% to under 1 mV. $69-$249. Dynamic Measurements Corp., 6 Lowell Ave., Winchester, MA 01809. Phone(617)729-7870.

Circle No. 221

DC/DC CONVERTERS MULTIPLY VOLTAGES, INVERT POLARITIES. Models are available in flatpack, 16-pin DIP and modular packages. Model PS1601F converts +5V to −5V at 25 mA. The PS1602F produces +15V at 20 mA from +5V, while the PS1603F accepts +12 to +15V and outputs inverted voltages at 120 to 130 mA. The PS1652M operates from +12 to +16V, and produces +250V at 20 mA, −12V at 50 mA and +5V at 160 mA. Commercial and military versions are available. LRC, Inc., 1001 Digital Dr., Hudson, NH 03051. Phone(603)883-9351.

Circle No. 222

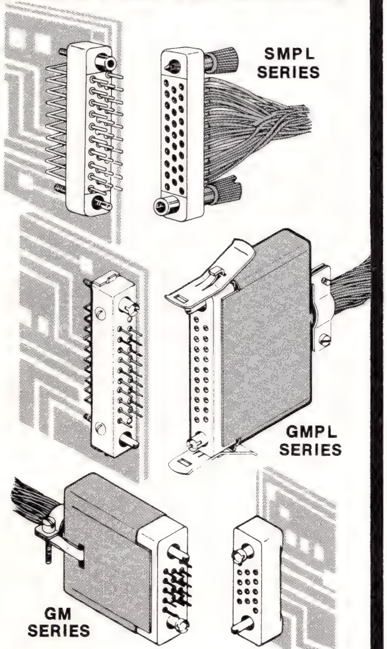
IF FILTER/EQUALIZERS FIT SATELLITE COMMUNICATION NEEDS. Available in 10 different models, one for each INTELSAT IV band, the filter, equalizer and amplifier are all housed in one rugged package. The units have an insertion loss of 0±1 dB, and are interchangeable with the GTE Italia 608-051/55-64 self-equalized IF filters. Amplitude and delay distortion are typ. tenths of a dB and 3 to 5 nsec, respectively. AIL, Deer Park, NY 11729. Phone(516)595-5823. **Circle No. 223**

MODULAR DC/DC CONVERTERS OFFER MULTIPLE OUTPUTS. Each supply in the Series 200 offers up to 4 independent regulated outputs. Each output is transformer isolated and short-circuit protected. Total output power is up to 15W for any combination. One available combination is ±15V at 0.25A, +5V at 1A and 200V at 10-20 mA. Dc inputs range from 11 to 54V. Modules start at $145 with delivery 6-8 wks. ARO. Powercube Corp., 214 Calvary St., Waltham, MA 02154. Phone(617)891-1830. **Circle No. 224**

XTAL DETECTOR FEATURES FIELD-REPLACEABLE DIODE ELEMENT. Model 1113 features freq. response flatness better than ±1 dB over the 0.1 to 18 GHz freq. range. Sensitivity is 0.4 mV/μW min. at low levels, and 100 mV/0.4 mW at high levels. VSWR is 2:1 max. Model 1113 is available with neg. (−1) or pos. (−2) output polarity. The diode element is easily replaced or reversed in the field without special tools. Weinschel Engineering, Gaithersburg, MD 20760. Phone(301)948-3434. **Circle No. 225**

For A Choice of Printed Circuit Mountable Connectors

Miniature and Sub-Miniature



Contact Positronics!

We offer both miniature and subminiature Pin and Socket Connectors for Printed Circuit mountable applications.

Right angle or vertically mounted styles are offered as standard and provide an easy way to make direct cable connections to a P/C board or flexible circuit. Greater contact densities can also be achieved.

Standard GM and SGM series connector accessories such as guides, threadlocks, and vibration locks are used on the SMPL and GMPL connectors so they can be mated with a standard GM or SGM series cable connector.

Contact configurations range from 5 to 50 contacts. Amperage ratings are 5 and 7½ amps.

AVAILABILITY: TWO TO FOUR WKS.
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For more information, Circle No. 68

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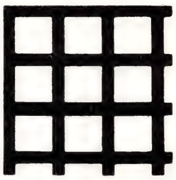
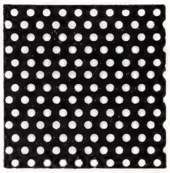
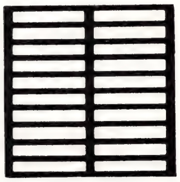
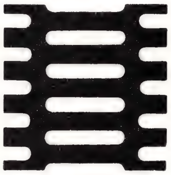
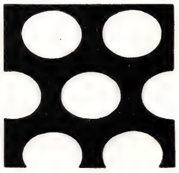
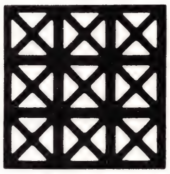

Square holes


Round holes


Slots


Oblong holes


Oval holes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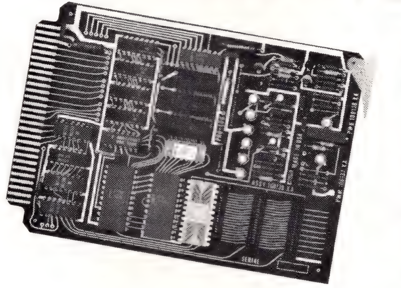
Microprocessors are Logic Elements... and Pro-Log can prove it!



Our 4-bit microprocessor system can replace a rack full of your TTL chips. You'll save design time and production costs. No big redesign jobs for options or changes because the logic is stored in reprogrammable ROMs. Our programmed logic systems are available now, off the shelf.

Our PLS-401 microprocessor system costs less than $400 in a quantity of one, with substantial OEM discounts. Plus we've got all the support you need: Design manuals, 3-day intensive design course, PROM Programmers, System Testers, special interface cards (including opto-isolator, triac, and driver cards) and support hardware to make your system go together smoothly.

Logic Processor Systems from Pro-Log

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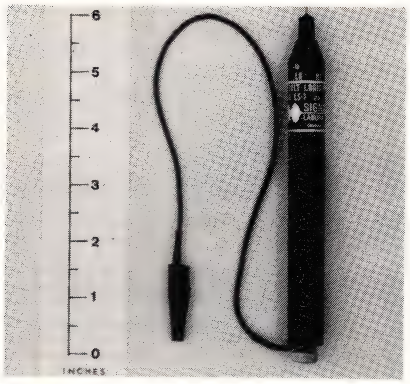
Call or write to 852 Airport Boulevard, Monterey, California 93940, (408) 372-4593

For more information, Circle No. 70



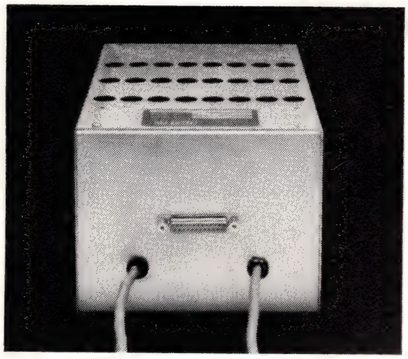
BATTERY - OPERATED LOGIC PROBE HANDLES ALL 5V SYSTEMS. Model LS-1 is usable with TTL, DTL, RTL, Schottky TTL, low-power TTL and CMOS logic circuits. No external power clips are required, and the LED indicators on its probe tip permit simultaneous viewing of the circuit point and indication. There is no power drain except when LED's are lit. Input impedance is 100 kΩ/10 pF. $77. Signal Laboratories, Inc., 187 N. State College Blvd., Orange, CA 92668. Phone(714)538-7280. **Circle No. 226**

PRERECORDED AVIATION, NAVIGATION AND FINANCE PROGRAMS are now offered for use with the HP-65 fully-programmable pocket-sized calculator. Aviation Pac I contains 29 different programs for use by pilots, including Aircraft Flight Plan with Wind. For marine navigators, Navigation Pac I lists 26 different programs such as Long Term Aries Almanac. There are 38 typical programs in the Finance Pac I, including ones for loans, savings and annuities. $45/Pac. Hewlett-Packard Co., 1501 Page Mill Rd., Palo Alto, CA 94304. Phone(415)493-1501. **Circle No. 227**

AUXILIARY NUMERIC KEYBOARD SPEEDS TELETYPE^{R} DATA ENTRY. Portable and easily connected to a teletype terminal, the auxiliary numeric keyboard increases throughput and eases numeric data entry. Its buffered storage lets it accept numbers in bursts, then feed them at TTY-acceptable rates. Both keyboards remain active at all times. $395. IDM, Box 954, Hanover, NH 03755. Phone(603)643-2840. **Circle No. 228**

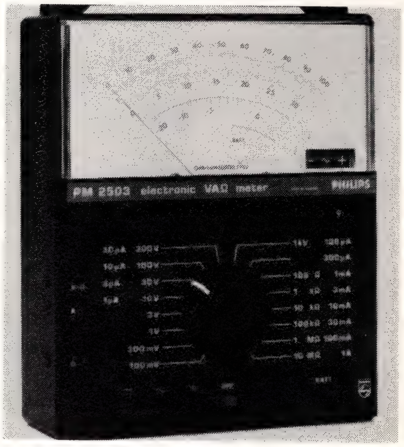
POWER MONITOR PROTECTS 3-PHASE MOTORS AND EQUIPMENT. Inputs to the Model 259 connect directly to the power lines at the point to be monitored. The output, a set of dpdt 10A contacts, will trip if there is a loss of phase, a low-voltage condition or a phase reversal. The unit features adjustable tripping delay from 1 to 5 sec and automatic reset. Standard models cover 120, 240, 480 and 575V ac, 50/60 Hz, wye or delta. Time Mark Corp., Box 15127, Tulsa, OK 74115. Phone(918)939-5811. **Circle No. 229**

SPEED OF OPTICAL PAGE READERS REACHES 1000 WORDS/MIN. Model 400, replacing Models 100, 200 and 300, reads to 110 cps, has only 2 electronic adjustments and returns the paper to the front of the unit. Model 500 is a Model 400 with a microprocessor added. The processor has 45 generalized computer instructions for tailoring the unit to each application's specific requirements. Datatype Corp., 1050 N.W. 163rd Dr., Miami, FL 33169. Phone(305)625-8451. **Circle No. 230**



TELECOMMUNICATION SYSTEM/TELEX INTERFACE can be used with virtually any type of terminal. The Series 10006 can be configured for use with single or multiline arrangements. A terminal line card meets standard line signaling criteria, and a 20-character programmable answerback is optional for systems that do not meet the Telex-system answerback requirements. $2000, up. NuData Corp., 32 Fairview Ave., Little Silver, NJ 07739. Phone(201)842-5757. **Circle No. 231**

ELECTRONIC COUNTER FEATURES BRIGHT PLANAR READOUT. With a total display range of 1 to 1999999, the Model 7026 has a frequency range of 5 Hz to 50 MHz and is guaranteed accurate to ±1 count. It operates from 117/234V ±10%, 50-60 Hz and draws 25W. Both compact and light weight (4×8.5 in. and 6.5 lbs.), it is moved easily to wherever needed. The rate of sampling can be adjusted from 5 readings/sec to hold. Simpson Electric Co., 853 Dundee Ave., Elgin, IL 60120. Phone(312)695-1121. **Circle No. 232**



LINEAR SCALES EXCEPT FOR dB MAKE MULTIMETER UNIQUE. Featuring voltage-range protection up to 2 kV, automatic polarity with indication and 10 MΩ input impedance, the PM2503 provides 3% worst-case accuracy. Current ranges are 1 μA to 1A; voltage ranges, 100 mV to 1000V; and resistance ranges 100Ω to 10 MΩ. No zeroing or infinity adjustments are required, and standard 9V batteries supply 1000 working hours before replacement. $169. Philips Test & Measuring Instruments, Inc., 400 Crossways Park Dr., Woodbury, NY 11797. Phone(516)921-8880. **Circle No. 233**

AUTOPOLARITY, OVERLOAD PROTECTION MARK 3-1/2-DIGIT DMM. Model 282 also offers automatically-positioned decimal point, 100% overrange capability, full overload protection and 10 mΩ input impedance on both ac and dcV. It reads to 1000V ac or dc, 1000 mA ac or dc and 10 MΩ resistance. Dc accuracy is 0.5%. $200. Dynascan Corp., 1801 W. Belle Plaine Ave., Chicago, IL 60613. Phone(312)327-7270. **Circle No. 234**

HTL LOGIC CHECKER JOINS DTL/TTL VERSION. The A23-2087's viewing screen is divided into 16 segments for easy pin identification. It's revised circuitry monitors positive logic HTL IC's with V_{cc} between +11 and +18V. The unit can be clipped either way round onto IC's with up to 16 pins. $120. Jermyn, 712 Montgomery St., San Francisco, CA 94111. Phone(415)362-7431.

Circle No. 235

KEMET FLAT KAP vs. NPO CERAMICS

Win the cost battle.

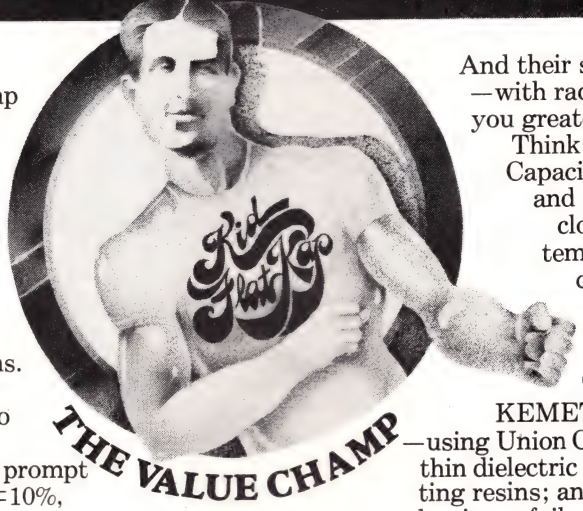
Specify new KEMET Flat Kap Parylene Thin-Film Capacitors.

They're now available in extended values from .001 uF to .22 uF for applications requiring small size, exceptional stability, and 0 ±50 PPM/°C. temperature coefficient of capacitance.

Reliability? They're built to meet MIL-C-55514 specifications. And designed for an operating temperature range of −55°C. to +125°C.

Choice? They're available for prompt delivery in three tolerances— ±10%, ±5% and ±1%.

Price? Above .01 uF, they're much lower in cost than NPO Ceramic Capacitors having essentially the same performance characteristics (see charts below).



And their small, rectangular cases—with radial or axial leads—give you greater volumetric efficiency.

Think how KEMET Flat Kap Capacitors can save you space and money in circuits where close tolerance, repeatable temperature coefficient and capacitance stability are essential.

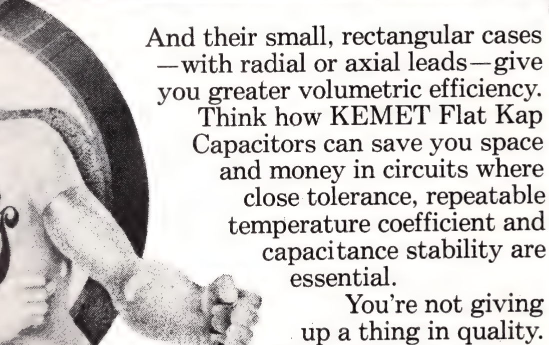
You're not giving up a thing in quality. The secret is the unique KEMET Flat Kap construction—using Union Carbide's Parylene ultra-thin dielectric film; special thermosetting resins; and precision, high-purity aluminum foil electrodes.

For high-reliability performance at lower cost, specify the value champ—new KEMET Flat Kap Parylene Precision Thin-Film Capacitors.

UNION CARBIDE
COMPONENTS DEPARTMENT
P.O. Box 5928, Greenville, S.C. 29606 Phone: (803) 963-7421 TWX: 810-287-2536

PERFORMANCE CHARACTERISTICS

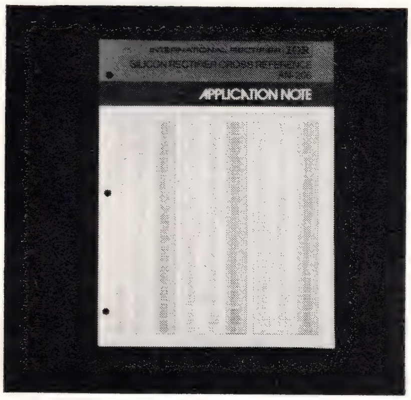
	FLAT KAP	NPO
Operating Temperature Range	−55° to +125°C.	−55° to +125°C.
Temperature Coefficient of Capacitance	0 ±50 PPM/°C.	0 ±30 PPM/°C.
Voltage Coefficient	Negligible	Negligible
Dissipation Factor @ 1 kHz	0.30% Max.	0.15% Max.
Insulation Resistance:		
Megohm-uF at 25°C.	10,000	1,000
Megohm-uF at 125°C.	100	100
Dielectric Absorption	1% Max.	0.5% Max.
Volume (0.05 uF Capacitor)	0.045 In.^{3}	0.0625 In.^{3}



KEMET is a registered trademark of Union Carbide Corporation

In Europe: Union Carbide Europe, S.A. 5. Rue Pedro-Meylan, Geneva 17, Switzerland Phone: 022/47 4411 Telex: 845-222 53

For more information, Circle No. 71


INTERNATIONAL RECTIFIER IOR
SILICON RECTIFIER CROSS REFERENCE
AN-206
APPLICATION NOTE

SILICON RECTIFIERS. A cross reference guide, AN-206, lists 2000 devices. This 10-pg. note also provides typical voltage code suffixes and IR rectifier case styles. International Rectifier Corp., 233 Kansas St., El Segundo, CA 90245.
Circle No. 236

FUNCTION MODULES. A 48-pg. product and applications guide features data on a wide range of function modules, including rms/dc converters, op amps, analog multiplier/dividers, multiplying DAC's, power supplies and dc/dc converters. Considerable information is supplied on product applications and definition of parameter specifications. Intronics, 57 Chapel St., Newton, MA 02158. **Circle No. 237**

FORCED AIR COOLING. Reprints of an article entitled, "Forced air cooling in high density systems," are now available. The article discusses how this type of cooling substantially improves system survival. Rotron Inc., Woodstock, NY 12498. **Circle No. 238**

MINIATURE BRUSHLESS DC MOTORS are described in a 12-pg. brochure. It highlights typical applications using these versatile motors, as well as covering their operating and design principles, key features, circuits for speed control, reversal and dynamic braking, performance curves and specifications. Siemens Corp., 186 Wood Ave. S., Iselin, NJ 08830. **Circle No. 239**

PRIMARY BREAKDOWN VOLTAGE. A brief critique of common methods of primary breakdown-voltage testing of power transistors is offered in 6-pg. application note AN-6281. The test set described is intended to fill the need for accurate, laboratory type sustaining-voltage measuring systems. RCA Solid State Div., Box 3200, Somerville, NJ 08876. **Circle No. 240**

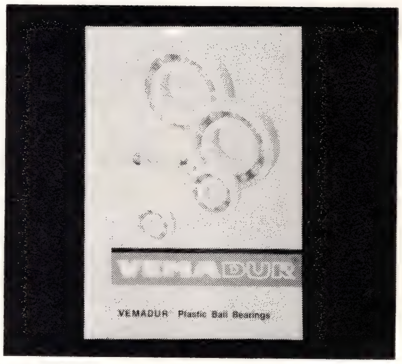
COMMUNICATIONS COMPONENTS. The entire product listing of TRW RF semiconductors is contained in this 20-pg. catalog (#500). UHF, VHF and microwave discrete transistors, mobile-radio amplifiers and transistors, and hybrid amps and discrete transistors for CATV are listed. TRW Semiconductors, 14520 Aviation Blvd., Lawndale, CA 90260. **Circle No. 241**

ALUMINUM PANELS. This 4-pg. brochure describes precision-sawed aluminum panels for electronic equipment. It lists uses, dimensional tolerances, specs and ordering information for both standard and custom panels. TCI Aluminum, 240 E. Rosecrans, Gardena, CA 90248. **Circle No. 242**

VIBRATION AND SHOCK CONTROL. Bulletin 916 emphasizes off-the-shelf bonded rubber mounts, flexible couplings and damping materials for the dissipation of mechanical energy. A basic section provides a detailed approach to specifying mounts based on load and deflection ratings obtainable with the bulletin's vibration efficiency curve. Lordco Supply, Box 8069, Erie, PA 16505. **Circle No. 243**

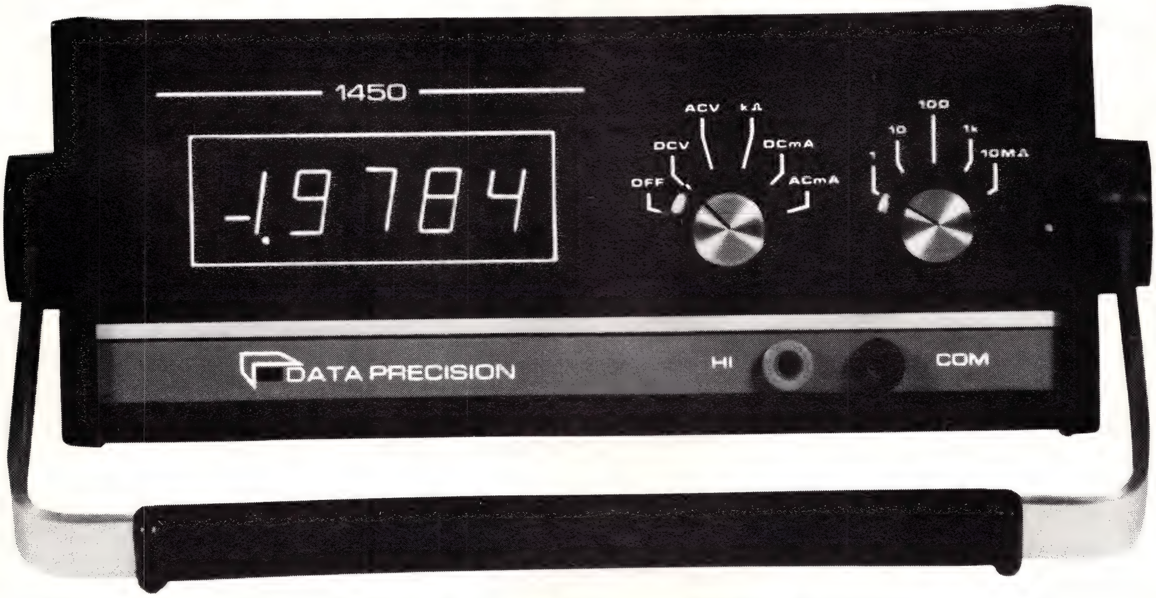
MAGNETIZING EQUIPMENT. An 8-pg. comprehensive guide describes the selection and use of simple to automated systems for magnetizing, testing, calibrating and stabilizing permanent magnets. All magnet materials are compared in terms of their saturation requirements and reactions to adverse fields, time and reluctance changes. Indiana General, 405 Elm St., Valparaiso, IN 46383.
Circle No. 244

CONFORMAL COATING METHOD, using the Parylene process, is the subject of this brochure. It describes this pinhole-free process, its electrical characteristics and its applications. Nova Tran Corp., 360 4th St., Box 386, Clear Lake, WI 54005. **Circle No. 245**



NONMETALLIC BALL BEARINGS that perform well in corrosive environments are described in this illustrated 8-pg. catalog. It lists specifications, applications, temperatures and tolerances. Helenor Trading Corp., 62 Marbledale Rd., Tuckahoe, NY 10707.
Circle No. 246

Data Precision Introduces A New 4-1/2 Digit DMM



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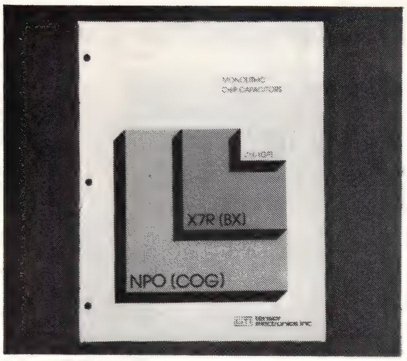
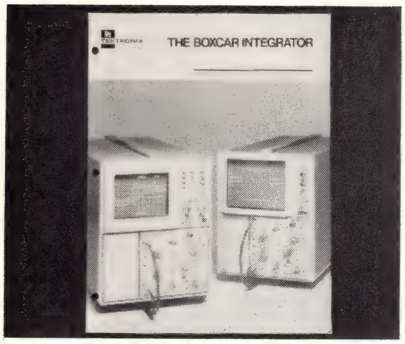
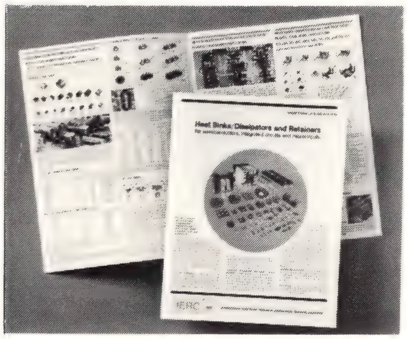


CAPACITORS. An 8-pg. brochure describes capacitance ranges, specifications and physical characteristics of ceramic chip capacitors. Included diagrams and graphs give easy reference. GTI/Tensor Electronics, Inc., 11558 Sorrento Valley Rd., San Diego, CA 92121. **Circle No. 248**



BOXCAR INTEGRATOR. App note #44L1.0 deals with boxcar signal integration using sampling-scope techniques to extend the measurement capability of a repetitive signal into the GHz frequency range. Tektronix Inc., Box 500, Beaverton, OR 97077. **Circle No. 249**



HEAT SINKS/DISSIPATORS. An 8-pg., short-form catalog details a comprehensive line of heat sinks, dissipators and other devices for thermal management. It gives all critical dimensions and includes performance curves for most dissipators. IERC, 135 W. Magnolia Blvd., Burbank, CA 91502. **Circle No. 250**

AMPLIFIERS. Fifty-two amplifiers, manufactured for special applications, are described in this short-form catalog. Included are general-purpose and power wideband amps, low-noise preamps, pulse and video amps and multicouplers. Units are available in modular form, rack mountable or laboratory instrument cases for dc or ac powering. C-COR Electronics, Inc., 60 Decibel Rd., State College, PA 16801. **Circle No. 251**

MATCHED LIMITER CHANNELS. App note AP401 notes the difficult problems encountered when aligning and testing IF limiters, and presents a solution using an amplitude sweeping test set. A typical test set up for making phase tracking measurements with the RHG Log Test Set is also diagrammed. RHG Electronics Laboratory, Inc., 161 E. Industry Ct., Deer Park, NY 11729. **Circle No. 252**

INSTRUMENTATION. This short-form, applications-oriented catalog describes the full line of precision transducers and instrumentation for sensing, measuring, and analyzing all aspects of sound and vibration. B & K Instruments, Inc., 5111 W. 164th St., Cleveland, OH 44142. **Circle No. 253**

LIMITERS. App note #2 discusses the use of limiters in communications equipment. Topics include receiver front-end protection and the design constraints of a communication limiter. A performance comparison between communication limiters and EW limiters is included. American Electronic Laboratories, Inc., Box 552, Lansdale, PA 19446. **Circle No. 254**

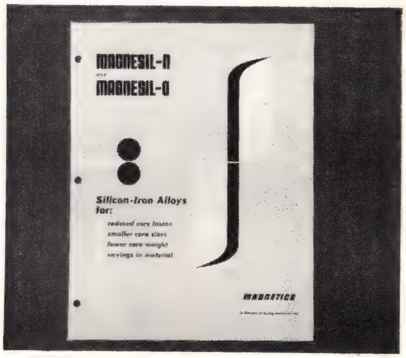
HEAT EXCHANGER CATALOG No. 30 presents information to help electronic engineers more easily design liquid systems to cool electronic components. This updated manual completely covers the important heat exchanger areas of water and air flow; pumps, fans and tubing layouts together with conversion data for special application problems. Wakefield Engineering Co., Aubudon Rd., Wakefield, MA 01880. **Circle No. 255**

MICROCOMPUTER DIGEST. This newsletter covers developments, applications, products and other areas of interest in the microcomputer industry. Microcomputer Associates, Inc., 2386-C Walsh Ave., Santa Clara, CA 95050. **Circle No. 256**

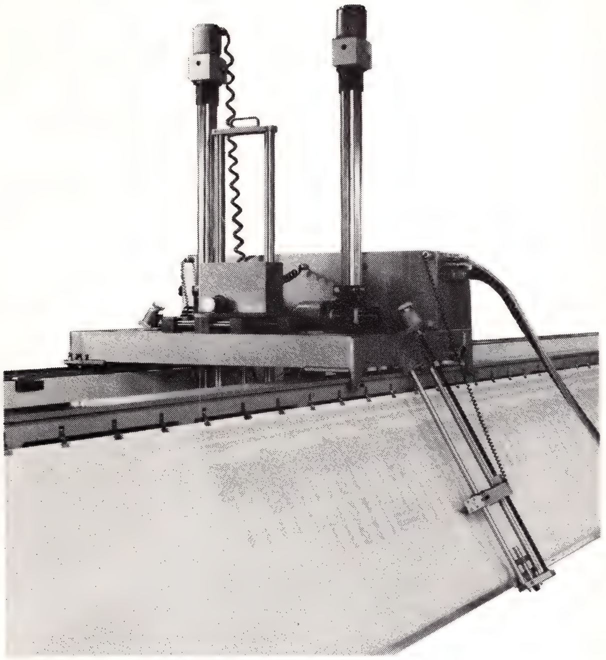
SOLID-STATE TIMERS. The brochure features pictures, specs and a mini-course in application and function of all the various types of timing modes. Information on proximity switches and the programmable controller is also included. Industrial Solid State Controls, Inc., 435 W. Philadelphia St., York, PA 17405. **Circle No. 257**

WAVEFORM RECORDER. The data sheet on the Model 610B waveform recorder tells how it can add storage to your scope. Its features are listed, and there is a section that describes the concept of a transient recorder. Biomation Corp., 10411 Bubb Rd., Cupertino, CA 95014. **Circle No. 258**

DIGITAL LOGIC RECORDER. A brief but fact-filled data sheet provides full information on the Model 810-D digital logic recorder. Photos, block diagrams, specs and performance curves define it fully. Biomation Corp., 10411 Bubb Rd., Cupertino, CA 95014. **Circle No. 259**



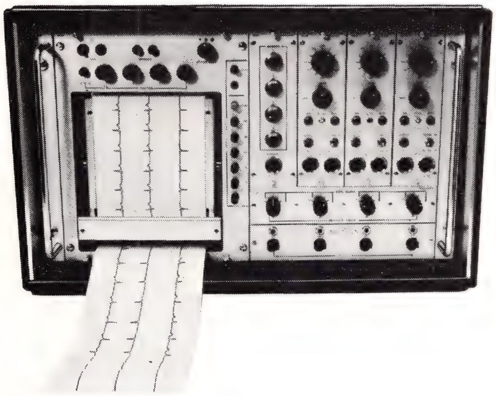
THIN ELECTRICAL STEELS. Catalog TES-100, a 28-pg. brochure, describes typical test data on 2 major types and 7 thin gauges of Magnesil^{R} silicon-iron electrical steels. Featured are easy-to-read design curves and other magnetic data that simplify material selection. Magnetics, Box 391, Butler, PA 16001. **Circle No. 260**



A Recorder...

If all recorder requirements were the same, it wouldn't make any difference what recording paper you used. All recording papers would be the same also.

But the recording equipment you design is unique. Its recording speed, dynamic range, resolution and other characteristics are not identical to all other recorders. So if you are going to get peak performance, you must use a recording paper which matches your unique design requirements.



is a recorder

At Fitchburg CPI we have ten different lines of coated recording paper. With literally hundreds of standard variations to meet practically every recording requirement. We have recording papers to meet the special requirements of sonar, computer print out, electrocardiograph, non-destructive testing, industrial event recording, photo facsimilies and voice characteristic sonagrams.

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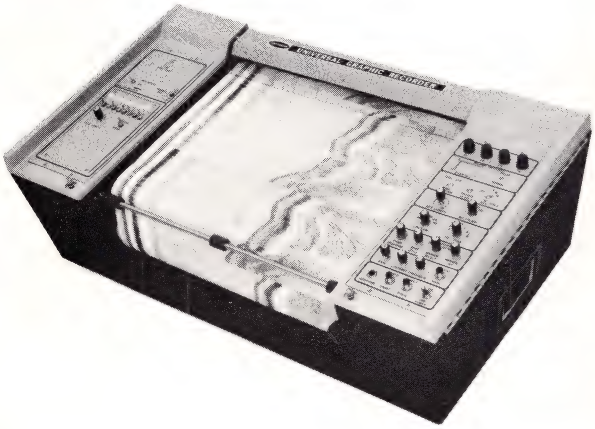

is a recorder

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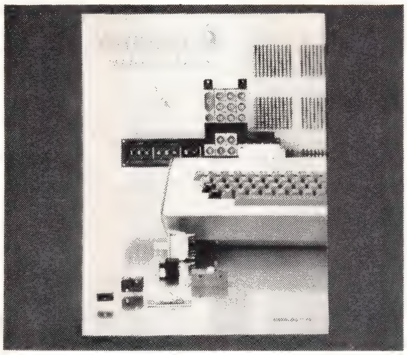


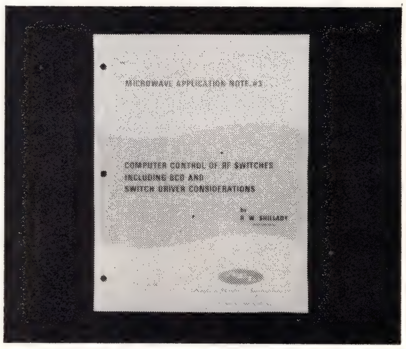
SWITCHES AND KEYBOARDS. The 72-pg. catalog, C-74, has been expanded and updated to offer complete listings, engineering drawings, operating characteristics and technical data on switches and keyboards. Among the items it includes are snap-action switches, leverwheel and thumbwheel switches, matrix selector switches, keyboards and keyboard switches. Cherry Electrical Products Corp., Box 718, Waukegan, IL 60085. **Circle No. 261**

RENTAL INSTRUMENTS. The 1974-75 Quick-Rental instruments catalog, GEP-1551A, describes hundreds of types of test instruments available on a rental basis. It lists the nationwide network of rental sales/service offices and inventory centers, plus related services for measurement consulting, instrument repair, and computer terminal service. General Electric Co., Bldg. 28, Schenectady, NY 12345. **Circle No. 262**

GENERATORS. This 6-pg. short-form catalog describes 31 different generator models. Included are function generators, phase generators, frequency synthesizers and complex waveform synthesizers. The catalog also contains a model capability cross-reference chart and prices. Exact Electronics, Inc., Box 160, Hillsboro, OR 97123. **Circle No. 263**

POWER FILM RESISTORS. This test report graphically illustrates the stability of the Type MP performance power film resistors as measured over 4-1/2 yrs. Eighteen resistors were subjected to continuous "Power ON-OFF" tests and the results show both the min. and max. changes and the average shift. Caddock Electronics, Inc., 3127 Chicago Ave., Riverside, CA 92507. **Circle No. 264**

THERMOMETER SYSTEM. A data sheet, punched for catalog reference use, gives the complete electrical and mechanical specs for a multi-temperature, pushbutton electronic thermometer system. Applications, prices, temp. ranges, accessory probes, panel or console installation and dimensions are all described in data sheet F-6417. Pak-Tronics, Inc., Dept. ET, 4044 N. Rockwell St., Chicago, IL 60618. **Circle No. 265**



MICROWAVE APPLICATION NOTE #3

COMPUTER CONTROL OF RF SWITCHES
INCLUDING BCD AND
SWITCH DRIVER CONSIDERATIONS

by
R. W. SHILLADY

RF SWITCHES. This 18-pg. microwave app note, #3, covers the interface requirements of RF switch drivers and the effect of drivers on the performance of these switches. Tables, figure drawings and photographs are included as illustrative material. American Electronic Laboratories, Inc., Box 552, Lansdale, PA 19446. **Circle No. 266**

MOS CIRCUITS. The MOS integrated circuit catalog contains over 500 pgs. of design and application information on standard MOS products. Items included are digital calculators, digital clocks, shift registers, memories, character generators, code converters and microprocessor elements. National Semiconductor, 2900 Semiconductor Dr., Santa Clara, CA 95057. **Circle No. 267**

IR's new glass passivated, high voltage Power Transistors and Darlingtons...

Better performance where it really counts.*

The three other largest selling high voltage power transistor lines of today offer you good characteristics. But while a specific device may excel in specs for one parameter, it may be marginal in other equally important characteristics. Not so with IR's new high voltage power transistors. They easily meet or exceed all established specifications. Now you can design a better, more efficient circuit without compromising.

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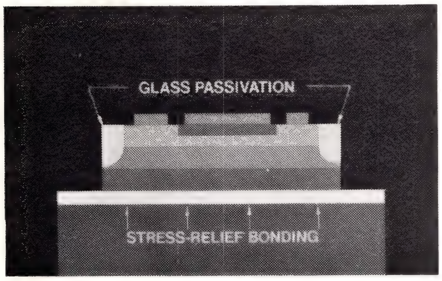
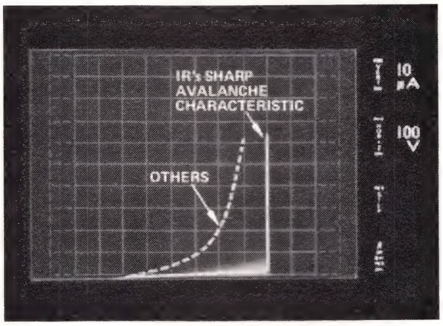
Most others offer you either high voltage or high gain. They can't give you both in the same device. We can. For example: rated to 700V_{CBO} with an I_C from 7 to 10 Amps (pulse), we provide a gain of 30 - 90 at 1 Amp.



* Glass Passivation for longer life, better stability.

IR triple-diffused, NPN mesa structures are the first and only high voltage power transistors with glass passivated junctions. You'll get longer life and a stability unequalled by the other brands.



The avalanche curve pictured shows our "sharp" curve and the "soft" curve of the others. Convincing evidence of better junctions that you can operate at full rated specs without a worry.

* Lower Saturation Voltage for better efficiency.

IR saturation voltage is lower than the others. Higher efficiency, less power loss, reduced power consumption and system operation at lower power levels are your new advantages. And you won't have to sacrifice switching speeds or voltage capability.

* "Stress-Relief" Bonding for better resistance to temperature cycling.

IR's "Stress-Relief" bonding between the chip and mounting surface gives better protection from thermal cycling, gives you an extra margin of safety in thermal design considerations, with a broad safe-area that is more than adequate for any application.

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Find IR's equivalent to the devices you're now using, then ask your local IR salesman, Rep or Distributor for complete specs and a test evaluation sample. When you've put it to the test, we think you'll agree. It's better — everywhere that counts.

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IR403	DTS 403		
IR409	DTS 409		
IR410	DTS 410	RCA410	MJ410
IR411	DTS 411	RCA411 2N5838 2N5839	MJ411 MJ1800 MJ3029 MJ3430
IR413	DTS 413	RCA413 2N5840	MJ413
IR423	DTS 423	RCA423	MJ423
IR424	DTS 424		MJ424
IR425	DTS 425		MJ425
IR430	DTS 430	2N5239 2N5240	MJ430
IR431	DTS 431	RCA431 2N5240	MJ431 2N5241
Monolithic Power Darlingtons			
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IR4045	DTS 4045		
IR4060	DTS 4060		
IR4065	DTS 4065		

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For more information, Circle No. 75

signals and noise

Numbers were multiplexed

Dear Sir,

In my article, "New multiplexing technique reduces system display cost" (EDN, Sept. 5, 1974, pp.61-63), two part numbers were incorrect. Z_{10} should be a 7404, while Z_{11} should be a 7414. Also, there should be no connection to the "0" output of Z_1 (74154). Outputs 1-15 drive the display's digit select drivers.

Very truly yours,
Don Alford
Microtel Systems
Dallas, TX

(Ed. Note: Seems as if we momentarily lost our decoder and got some signals crossed when re-drawing the diagram.)

Active and digital filter reprints

In answer to the many requests for reprints of EDN's Designers' Guides to Digital and Active Filters, we have bound each set together. See the ads in this issue for complete ordering information.

Roy Forsberg
Editor

It's about time!

Then there's the story about the somewhat slow fellow who sat on his digital dock. In great pain he rushed to a doctor, who pulled the LED out of his tail.

How true

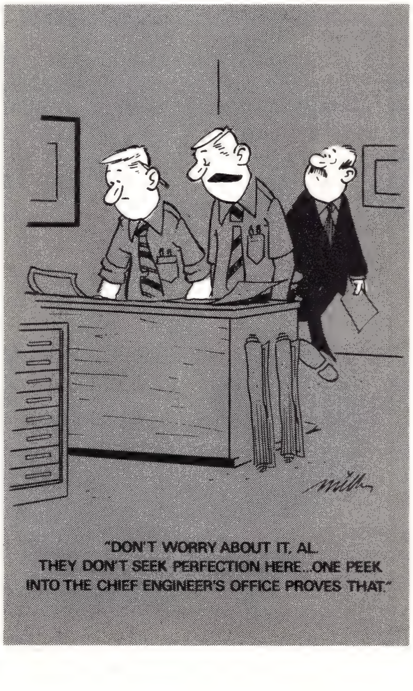
"A new product is the easiest thing to keep down, and the hardest thing to defend."

"On Research—a collection of quotations," Arthur D. Little, Inc.

Want to travel?

Gentlemen:

Our intensive short courses on microprocessors and microcomputers are being enthusiastically received. We thank you for your cooperation and assistance in providing such excellent reference material. Keep up your pioneering work!



"DON'T WORRY ABOUT IT, AL.
THEY DON'T SEEK PERFECTION HERE...ONE PEEK
INTO THE CHIEF ENGINEER'S OFFICE PROVES THAT."

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Nov. 6-8	Washington, DC
Nov. 12-14	Miami Beach, FL
Nov. 19-21	Copenhagen, Denmark
Nov. 26-28	London, England
Dec. 3-5	Rome, Italy
Dec. 9-11	Tel Aviv, Israel

Very truly yours,
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Integrated Computer Systems
12561 Appleton Way
Mar Vista, CA 90066

Flashback to foldback...

Gentlemen:

R. J. Haver, in his Aug. 20, 1974 article on current foldback, noted "...the drawback to this protection method is a slight decrease in efficiency...."

A solution to this drawback is to return the bottom of R_3 to a positive reference of a value up to or exceeding V_{OUT}. In **Fig. 4** of the article, for example, R_3 may be returned to pin 2 of the MPC1000. Then, if the new circuit equations are developed, R_1 is reduced both in value and power rating, while R_2 and R_3 have new optimum values. Short-circuit current is easily reduced to a few mA, relieving the pass transistor's SOA problems. Moreover, in some designs V_{IN} can be reduced, resulting in greater efficiency and less heat generation.

Sincerely,
Arthur R. Kopp, Project Engineer
Optical Scanning Corp.
Newtown, PA

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with a WJ-1300 ADATE* SYSTEM

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- A complete selection of special options available from Watkins-Johnson.

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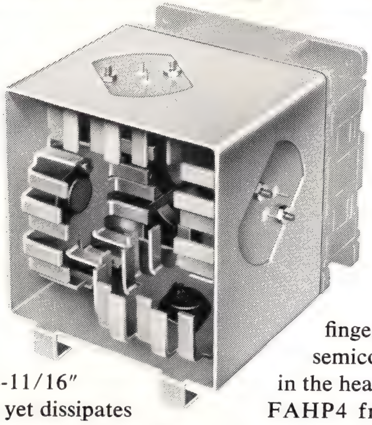
For more information, Circle No. 76

New forced air cooling package dissipates 450 watts; costs only $6.50*



*1000-pc qty.; fan not included.

Our new Series FAHP4 blower package measures only 3-3/4" x 5-3/16" x 4-11/16" and weighs only 14 ounces, yet dissipates 450 watts in a 25°C ambient with a case rise of less than 95°C. The secret to its high performance and low cost is the use of four standard IERC HP3 staggered finger heat sinks. Since the semiconductor hole pattern is in the heat sinks we assemble the FAHP4 from standard off-the-shelf heat sinks and shrouds. Ask for our new data sheet. IERC, 135 W. Magnolia Blvd., Burbank, Calif. 91502, a subsidiary of Dynamics Corporation of America.

IERC DCA Heat Sinks

For more information, Circle No. 77

CUSTOM ELECTRONICS' MICA CAPACITORS: short on DELIVERY long on RELIABILITY

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CMRIA302104K	0.1 μf	3,000	2.562" × 1.620" × 0.270"	9.25
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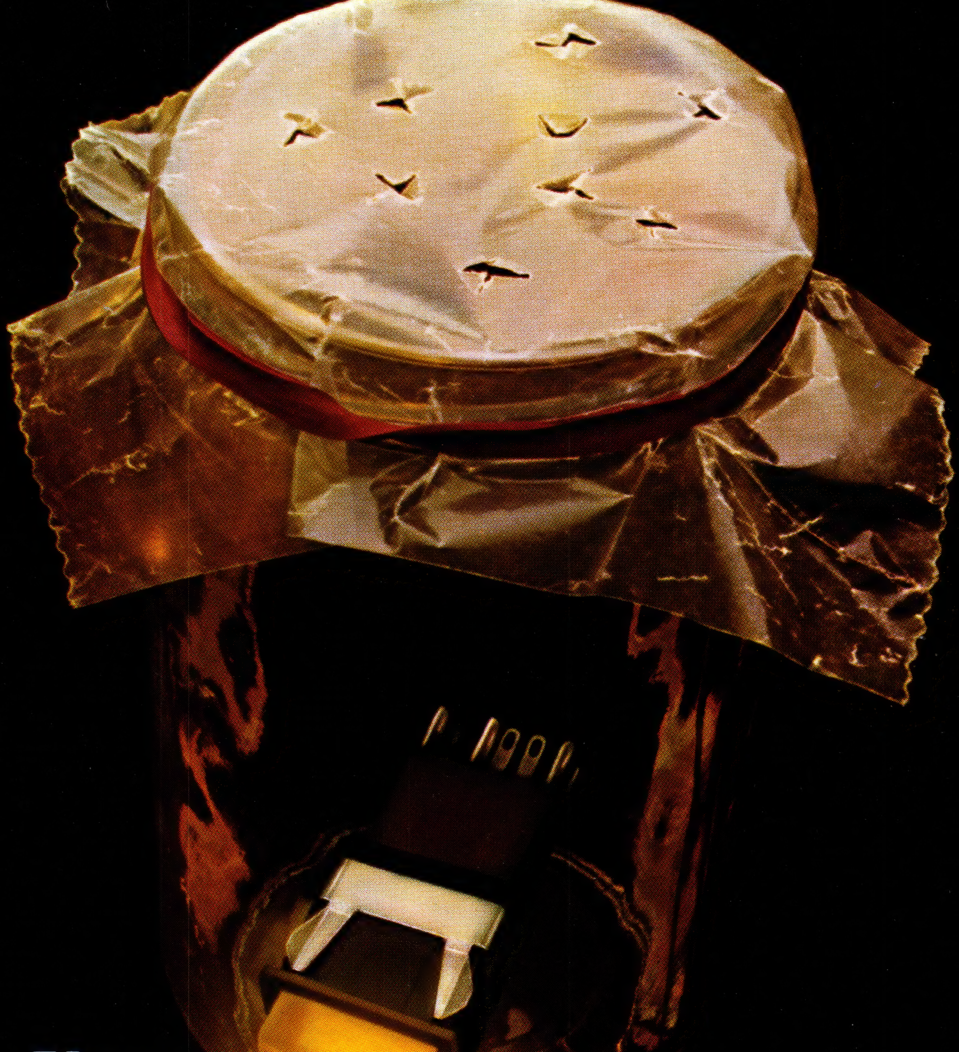

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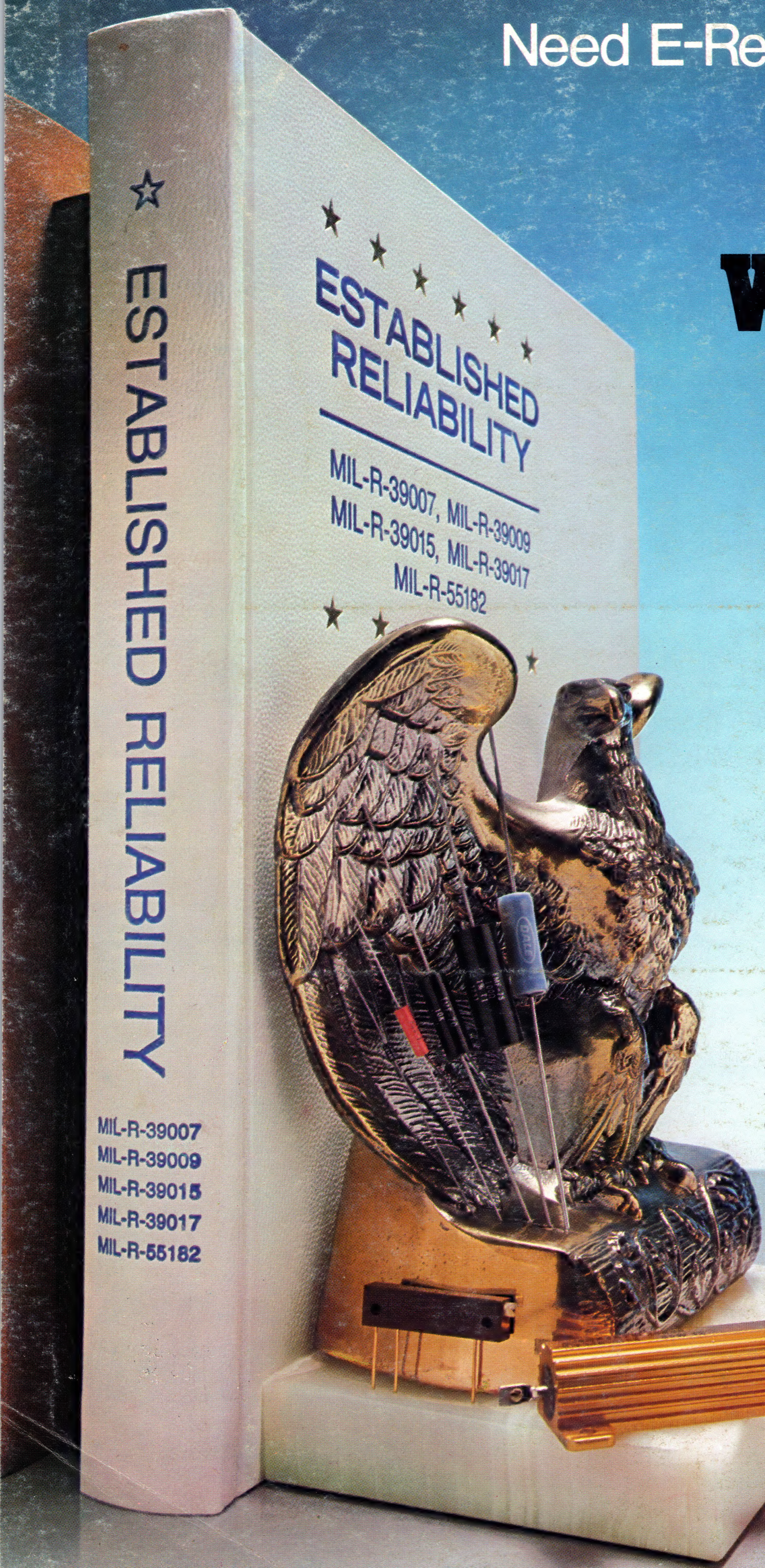

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